NASA AUTHORIZATION FOR FISCAL YEAR 1961

HEARINGS

BEFORE THE

NASA AUTHORIZATION SUBCOMMITTEE

OF THE

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES UNITED STATES SENATE

EIGHTY-SIXTH CONGRESS

SECOND SESSION

ON

H.R. 10809

AN ACT TO AUTHORIZE APPROPRIATIONS TO THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION FOR SALARIES AND EXPENSES, RESEARCH AND DEVELOPMENT, CONSTRUCTION AND EQUIPMENT, AND FOR OTHER PURPOSES

JUNE 30, 1960

PART 2
SCIENTIFIC AND TECHNICAL ASPECTS OF NASA PROGRAM

Printed for the use of the Committee on Aeronautical and Space Sciences

UNITED STATES
GOVERNMENT PRINTING OFFICE
53795 O WASHINGTON : 1960

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C. - Price $1.25

SENATE COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES

LYNDON B. JOHNSON, Texas, *Chairman*

RICHARD B. RUSSELL, Georgia
WARREN G. MAGNUSON, Washington
CLINTON P. ANDERSON, New Mexico
ROBERT S. KERR, Oklahoma
STUART SYMINGTON, Missouri
JOHN STENNIS, Mississippi
STEPHEN M. YOUNG, Ohio
THOMAS J. DODD, Connecticut
HOWARD W. CANNON, Nevada

STYLES BRIDGES, New Hampshire
ALEXANDER WILEY, Wisconsin
MARGARET CHASE SMITH, Maine
THOS. E. MARTIN, Iowa
CLIFFORD P. CASE, New Jersey

KENNETH E. BELIEU, *Staff Director*
MAX LEHRER, *Assistant Staff Director*
EVERARD H. SMITH, Jr., *Counsel*
WILLIAM J. DEACHMAN, *Assistant Counsel*
Dr. GLEN P. WILSON, *Chief Clerk*
Dr. EARL W. LINDVEIT, *Assistant Chief Clerk*

NASA AUTHORIZATION SUBCOMMITTEE

JOHN STENNIS, Mississippi, *Chairman*

STEPHEN M. YOUNG, Ohio
THOMAS J. DODD, Connecticut
HOWARD W. CANNON, Nevada

MARGARET CHASE SMITH, Maine
THOS. E. MARTIN, Iowa

MAX LEHRER, *Professional Staff Member*

DEPOSITED BY THE
UNITED STATES OF AMERICA

LETTER OF SUBMITTAL

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,
OFFICE OF THE ADMINISTRATOR,
Washington, D. C. June 27, 1960.

Hon. JOHN STENNIS,
Chairman, NASA Authorization Subcommittee of the Committee on Aeronautical and Space Sciences, U.S. Senate, Washington, D.C.

DEAR SENATOR STENNIS: In accordance with the request of your subcommittee, we are furnishing herewith material relating to the scientific and technical aspects of the National Aeronautics and Space Administration program, which material is to be made a part of the hearings on H.R. 10809, an act to authorize appropriations to the National Aeronautics and Space Administration for fiscal year 1961.

Some of this material deals with basic scientific and technical data which were initially presented to your subcommittee during its hearings on S. 1582 on April 7, 8, 9, and 10, 1959. The original information has been thoroughly reviewed, revised where required, and new information has been added so that the entire compilation represents an up-to-date summary of NASA's scientific and technical programs.

As requested, the additional material retains its original flavor, which I believe you will agree makes for easier reading of some of these difficult technical subjects.

You will find in this accompanying material discussion of the technical problems NASA is working on today in space sciences, in manned space flight, in tracking and data acquisition, in propulsion, in research, and in the life sciences. In testifying before another Senate committee, I said, concerning last year's volume, that it was "* * * the most comprehensive, understandable, and educational document on the Federal Government's aeronautical and space activities that exists today." It is our hope that the current volume will also merit that description and will prove to be useful to your committee, to the Congress, and to the scientific community.

Sincerely,

T. KEITH GLENNAN, *Administrator.*

CONTENTS

	Page
I. Space sciences:	
"Atmospheres," by Dr. Homer E. Newell, Deputy Director, Office of Space Flight Programs, NASA	575
"Ionospheres," by Dr. John F. Clark, Chief, Geophysics Programs, NASA	584
"Energetic Particles," by Dr. Leslie H. Meredith, Chief, Space Sciences Division, NASA Goddard Space Flight Center	594
"Fields," by Dr. Robert F. Fellows, Assistant Chief, Geophysics Programs, NASA	599
"Astronomy," by Dr. John A. O'Keefe, Assistant Chief, Theoretical Division, NASA Goddard Space Flight Center	610
"Lunar Exploration," by E. M. Cortright, Assistant Director, Lunar and Planetary Programs, and J. Allen Crocker, Chief, Program Coordination, Lunar and Planetary Programs, NASA	617
"Midcourse and Terminal Guidance," by Benjamin Milwitzky, Head, Geodetic and Navigational Satellites Program, NASA	624
"Space Sciences Summary," by Dr. Homer E. Newell, Deputy Director, Office of Space Flight Programs, NASA	632
II. Applications programs:	
"Meteorological Satellites," by Dr. Morris Tepper, Chief, Meteorological Satellite Program, NASA	643
"Communications," by Leonard Jaffe, Chief, Communications Satellite Program, NASA	668
"Geodesy," by Benjamin Milwitzky, Head, Geodetic and Navigational Satellites Program, NASA	685
III. "Manned Space Flight," by George M. Low, Chief, Manned Space Flight Program, NASA	697
IV. "Tracking and Data Acquisition," by Francis B. Smith, Chief, Advanced Development, Space Flight Operation, NASA	747
V. Propulsion:	
"Launch Vehicle Program," by Abraham Hyatt, Deputy Director, Launch Vehicle Programs, NASA	777
"Space Propulsion," by Wolfgang E. Moeckel, Chief, Advanced Propulsion Division, NASA Lewis Research Center, Cleveland, Ohio	791
"Electric Rockets," by J. Howard Childs, Chief, Electric Propulsion Branch, NASA Lewis Research Center, Cleveland, Ohio	805
"Electrical Power for Spacecraft," by Robert E. English, Associate Chief, Power Production and Shielding Branch, Nuclear Reactor Division, NASA Lewis Research Center, Cleveland, Ohio	814
"Nuclear Rockets," by Harold B. Finger, Chief, Nuclear Engines Program, NASA	824
"One and a Half Million Pound Thrust Rocket Booster Engine Capabilities," by A. O. Tischler, Chief, Liquid Fuel Rocket Engines Program, NASA	977
"Nuclear Propulsion for Air-Breathing Engines," by William H. Woodward, Chief, Powerplants Research Division, NASA	981
VI. Research Programs:	
"Entry into Planetary Atmosphere," by Dr. Dean R. Chapman, research scientist, High-Speed Research Division, NASA Ames Research Center, Moffett Field, Calif	835
"Materials Research," by G. Mervin Ault, Assistant Chief, Materials and Structures Research Division, NASA Lewis Research Center, Cleveland, Ohio	847
"Space Structures," by Richard R. Heldenfels, Chief, Structures Research Division, NASA Langley Research Center, Hampton, Va	855

VI. Research Programs—Continued
"Vertical Takeoff and Landing Aircraft," by John P. Campbell, Head, Dynamic Stability Branch, Aerospace Mechanics Division, NASA Langley Research Center, Hampton, Va ... Page 867
"Noise," by Harvey H. Hubbard, Head, Acoustics Branch, Dynamic Loads Division, NASA Langley Research Center, Hampton, Va ... 876
"Supersonic Aircraft," by Herbert A. Wilson, Chief, Unitary Plan Wind Tunnel Division, NASA Langley Research Center, Hampton, Va ... 888
"High Speed Aircraft Engines," by Bruce T. Lundin, Assistant Director, NASA Lewis Research Center, Cleveland, Ohio ... 900
"Hypersonic Vehicles," by John V. Becker, Chief, Aero-Physics Division, NASA Langley Research Center, Hampton, Va ... 909
"Structure for Hypersonic Vehicles," by Roger A. Anderson, Head, Structural Configurations Branch (formerly Airframe Components Branch), Structures Research Division, NASA Langley Research Center, Hampton, Va ... 914
"Human Problems in Operation of High-Speed Vehicles," by Hubert M. Drake, Assistant Chief Research Division, NASA Flight Research Center, Edwards, Calif ... 920
"Flight Research Projects," by DeElroy Beeler, Assistant Director NASA Flight Research Center, Edwards, Calif ... 928
"Missile Design," by Milton B. Ames, Jr., Deputy Director, Advanced Research Programs, NASA ... 932
"Flight Characteristics of Missiles," by H. Julian Allen, Chief, High-Speed Research Division, NASA Ames Research Center, Moffett Field, Calif ... 941
"Structural Dynamics," by Dr. John C. Houbolt, Assistant Chief, Dynamic Loads Division, NASA Langley Research Center, Hampton, Va ... 951
"Interceptor Missiles," by David G. Stone, Head, Stability and Controls Branch, Pilotless Aircraft Research Division, NASA, Langley Research Center, Hampton, Va ... 965
VII. "The Life Sciences Program," by Clark T. Randt, M.D., Office of Life Science Programs, NASA ... 971
Appendix, "United States and Russian satellites, lunar probes and space probes, 1957 to June 1960" ... 987
Index ... 1007

ALPHABETICAL LIST OF CONTRIBUTORS AND SUBJECT MATTER PRESENTED

Allen, H. Julian, "Flight Characteristics of Missiles" ... 941
Ames, Milton B., "Missile Design" ... 932
Anderson, Roger A., "Structure for Hypersonic Vehicles" ... 914
Ault, G. Mervin, "Materials Research" ... 847
Becker, John V., "Hypersonic Vehicles" ... 909
Beeler, DeElroy, "Flight Research Projects" ... 928
Campbell, John P., "Vertical Takeoff and Landing Aircraft ... 867
Chapman, Dr. Dean R., "Entry Into Planetary Atmosphere" ... 835
Childs, J. Howard, "Electric Rockets" ... 805
Clark, Dr. John F., "Ionospheres" ... 584
Cortright, E. M., and Crocker, J. Allen, "Lunar Exploration" ... 617
Crocker, J. Allen, and Cortright, E. M., "Lunar Exploration' ... 617
Drake, Hubert M., "Human Problems in Operation of High-Speed Vehicles" ... 920
English, Robert E., "Electrical Power for Spacecraft" ... 814
Fellows, Dr. Robert F., "Fields" ... 599
Finger, Harold B., "Nuclear Rockets" ... 824
Heldenfels, Richard R., "Space Structures" ... 855
Houbolt, Dr. John C., "Structural Dynamics" ... 951
Hubbard, Harvey H., "Noise" ... 876
Hyatt, Abraham, "Launch Vehicle Program" ... 777
Jaffe, Leonard, "Communications" ... 668
Low, George M., "Manned Space Flight" ... 697

Page

Lundin, Bruce T., "High-Speed Aircraft Engines" 900
Meredith, Dr. Leslie H., "Energetic Particles" 594
Milwitzky, Benjamin, "Midcourse and Terminal Guidance" 624
Milwitzky, Benjamin, "Geodesy" 685
Moeckel, Wolfgang E., "Space Propulsion" 791
Newell, Dr. Homer E., "Atmospheres" 575
Newell, Dr. Homer E., "Space Sciences Summary" 632
O'Keefe, Dr. John A., "Astronomy" 610
Smith, Francis B., "Tracking and Data Acquisition" 747
Tepper, Dr. Morris, "Meteorological Satellites" 643
Wilson, Herbert A., "Supersonic Aircraft" 888

LIST OF FIGURES

Figure

1. Structure of the Earth's atmosphere 576
2. Mass spectrometer for measurement of gas composition 579
3. Venus and Earth 581
4. Moon and Mars 582
5. Jupiter and Saturn 583
6. Ionospheres 585
7. Average summer noon ionosphere 587
8. Ionospheres research objectives 589
9. Long-range ionospheres program 590
10. Short-range ionospheres program 592
11. Ionosphere topside sounder 593
12. Auroras 595
13. Effect of latitude and altitude on cosmic ray intensity 597
14. Cosmic ray energy and charge spectrum 598
15. Great radiation belt 600
16. Earth's magnetic field 601
17. Compression of magnetic field 603
18. Captured particle distortion of magnetic field 604
19. Magnetic fields in interplanetary space 606
20. Earth's shape from orbit of Vanguard satellite 607
21. Atomic clock relativity test 609
22. The electromagnetic spectrum 612
23. Particles in space 614
24. Rough-landing spacecraft for Atlas-Agena 622
25. Spacecraft for Centaur planetary probe 623
26. Space guidance systems 625
27. Midcourse navigation systems 627
28. Terminal guidance 630
29. Attitude control 631
30. World radiosonde network 644
31. Atlas photograph of clouds and storm regions 648
32. First cloud cover satellite 650
33. Explorer VII 652
34. Long-wave radiation loss 653
35. Tiros 655
36. Photographs taken from Tiros I 658
37. Photograph taken from Tiros I 659
38. Photograph taken from Tiros I 660
39. Photograph taken from Tiros I 661
40. Photographs taken from Tiros I 662
41. Cloud system associated with a cold front 663
42. Meteorological satellite development 665
43. Mockup model of Nimbus 666
44. Passive communications satellite 670
45. Passive communications satellite experiment 672
46. Global communications coverage 673
47. Active repeater satellite 675
48. Active repeater—24-hour orbit 676
49. Space communication system 678
50. Telemetering system 679
51. Radio power for deep space probes 680
52. Techniques for reducing picture transmission power 682
53. Antenna systems for space probes 684

Figure		Page
54.	Goldstone station capabilities	686
55.	Section through Earth	688
56.	Effects of Earth's oblateness	690
57.	Earth's shape from orbit of Vanguard satellite	692
58.	World triangulation chart	693
59.	Methods of observing a geodetic satellite	694
60.	Geodetic satellite	696
61.	Project Mercury—Capsule system	698
62.	Project Mercury—Ballistic capsule	699
63.	Project Mercury—Pilot's instrument panel	701
64.	Project Mercury—Flight trajectory	702
65.	Model of capsule and escape tower in supersonic wind tunnel	705
66.	Full-scale capsule models in various stages of construction	706
67.	Airplane drop test of Mercury capsule	707
68.	Capsule impact after drop test	708
69.	Helicopter pickup of capsule following drop test	709
70.	Off-the-pad abort test of escape system	711
71.	Assembly of Little Joe vehicle	712
72.	Monkey in supporting couch prior to flight, with Dr. W. Lynn Brown of University of Texas	713
73.	Little Joe launching	715
74.	Retrieval of capsule after Little Joe flight	716
75.	Big Joe capsule being lifted to top of gantry	717
76.	Big Joe prior to launch	718
77.	Launching of Big Joe	719
78.	Recovered Big Joe capsule after flight from Cape Canaveral	721
79.	Mercury capsule mockup	722
80.	Construction of capsule's pressure vessel	723
81.	Capsule production line at McDonnell	725
82.	Project Mercury Redstone ballistic flights	726
83.	Project Mercury Atlas ballistic flights	728
84.	Project Mercury recovery areas	729
85.	Mercury Astronauts Carpenter, Slayton, Cooper, Shepard, Glenn, Grissom, Schirra	732
86.	Human centrifuge at Johnsville Navy Development Center	734
87.	Astronaut Grissom during a high-g run on centrifuge	735
88.	Air-bearing attitude simulator	736
89.	Gimballed attitude simulator	737
90.	Astronaut Schirra after egress from capsule in simulated high sea condition	738
91.	Three astronauts in weightless flight	739
92.	Astronaut Slayton in Mercury pressure suit	741
93.	Project Mercury flight schedule	746
94.	Elements of space flight launch, control and tracking network	748
95.	Polar, equatorial, and intermediate orbits	750
96.	Lunar or planetary trajectories	751
97.	Typical launch facilities	753
98.	Ground stations and downrange supporting facilities	755
99.	Baker-Nunn Photographic Satellite Tracking Station	758
100.	Photographic track of satellite	759
101.	SAO Baker-Nunn cameras	760
102.	Minitrack station	761
103.	Minitrack network	762
104.	Lunar probe TLM–18 antenna	763
105.	High inclination orbits	765
106.	Eighty-five-foot diameter parabolic antenna	766
107.	Deep space coverage from three stations	767
108.	List of Mercury stations	769
109.	FPS–16 tracking radar	771
110.	Basic Vanguard-minitrack communication network	772
111.	Typical network data flow chart	774
112.	Minitrack control and computing facilities	775
113.	U.S. vehicles, short-term use	778
114.	Scout	780
115.	Scout	781
116.	Delta	782

Figure		Page
117.	Delta	783
118.	Thor-Agena B	784
119.	Thor-Agena B	785
120.	Atlas-Agena B	787
121.	Atlas-Agena B	788
122.	Centaur	789
123.	Centaur	790
124.	Saturn	792
125.	Saturn	793
126.	Nova	794
127.	U.S. vehicles	795
128.	Requirements for launching 8-man expedition to Mars	796
129.	Electric rocket propulsion principles	799
130.	Escape trajectories with low-thrust propulsion system	801
131.	Minimum-energy flight path for Mars round trip	802
132.	Electric space vehicle for 8-man Mars expedition	804
133.	Simplified diagram of ion rocket	806
134.	Ion rocket test facility	809
135.	Ion rocket test facility	810
136.	Model of ion rocket	811
137.	Plasma accelerator	813
138.	Plasma accelerator	815
139.	Solar batteries	817
140.	Solar collectors	818
141.	High temperature yields low weight	820
142.	Raising satellite to 24-hour orbit	822
143.	Space probe to Mars, one-way trip	823
144.	Fission process	825
145.	Nuclear rocket components	826
146.	High impulse gives low propellant weight	828
147.	Mars orbit mission	829
148.	Nuclear rocket program goals	830
149.	Kiwi-A reactor	832
150.	Flight test vehicle	833
151.	Rocket braking	836
152.	Multiple-pass atmosphere braking	838
153.	Single pass entries	839
154.	Guidance problem for manned spaceship	840
155.	Entry corridors	842
156.	Heating rates during entry	843
157.	Relative heat-shield weights if heat is absorbed	845
158.	Satellite entry problems for various planets	846
159.	Some materials of high melting point	850
160.	Strength of metals at high temperatures	852
161.	Materials problems in space	854
162.	Strength of pure iron as diameter of specimen decreases	856
163.	Unmanned erectable satellite	858
164.	Erection techniques	860
165.	Manned satellites	862
166.	Meteorite damage	864
167.	Spaceship structures	866
168.	VTOL research models	868
169.	VTOL research airplanes	870
170.	Propeller VTOL transport	871
171.	Rotor configurations	873
172.	Ducted fan configurations	874
173.	Turbojet configurations	875
174.	Significance of noise levels	877
175.	Sources of turbojet engine noise	879
176.	Noise-suppression nozzles	880
177.	Noise-induced structural damage	881
178.	Supersonic transport noise problems	883
179.	Boundary layer noise	884
180.	Climb schedules to avoid sonic boom damage	886
181.	Space vehicle internal noise	889
182.	Increasing noise levels	890
183.	Flight efficiency	891

Figure		Page
184.	Drag components	893
185.	Stability problems	894
186.	New York-Paris flight plan	896
187.	Variable geometry	898
188.	Variable-sweep transport	899
189.	Performance comparison	901
190.	Chemical air-breathing propulsion	902
191.	Future engines	904
192.	Ram jet engine temperatures	906
193.	Ram jet flight speed limits	907
194.	Descent of global-range gliders	911
195.	Reentry of satellite vehicles	913
196.	Temperatures for hypersonic flight	915
197.	Heated structures design	917
198.	Oxidation of molybdenum specimens	918
199.	Stationary simulator	921
200.	Simulation by centrifuge	923
201.	Views of three-axis side-located controller	925
202.	Landing approach conditions	927
203.	X–15 typical mission	931
204.	X–15 aerodynamic heating	933
205.	Structural temperatures	934
206.	Wedge airfoils	937
207.	Wind vibrations	939
208.	Launching and stage separation problems	940
209.	Ballistic missile trajectories	942
210.	Maximum deceleration during entry	944
211.	Static stability	946
212.	Total heating	948
213.	Flow about slender and blunt bodies	949
214.	Effect of shape on velocity	952
215.	The aeroelastic rectangle	955
216.	Current sources of structural dynamics problems	956
217.	Some current structural dynamics problems	958
218.	Recent NASA flutter studies	959
219.	Flutter and flight boundaries	960
220.	Effect of engine location	962
221.	Factors designing a specific missile	963
222.	Interceptor missiles	966
223.	Reentry detection vehicle	968
224.	Throat section of 1,500,000 pound thrust rocket booster engine	978
225.	High thrust test area	980
226.	Edwards Air Force Base rocket test stand 1–A	982
227.	Nuclear powered turbojet direct-air heating system	984
228.	Nuclear powered turbojet closed heat-exchange system (liquid or gas)	985

NASA AUTHORIZATION FOR FISCAL YEAR 1961

I. SPACE SCIENCES

ATMOSPHERES

By Dr. Homer E. Newell, Deputy Director, Office of Space Flight Programs, NASA

Scientists have been interested in the upper atmosphere and space for a long, long time. This earliest of sciences goes back in history for hundreds and thousands of years. However, the tools that were available for research centuries ago were not as powerful as those we have today. The first attempt at direct exploration of the upper atmosphere occurred in 1749 when Dr. Wilson F. Glasgow sent up a kite. From the use of a kite man went to balloons, and later manned balloons. Free balloons are now used extensively in weather observations. Aircraft and giant balloons have also been used. Now we have rockets which can be used for space probes, for the launching of satellites, and for the sounding of the atmosphere.

Prior to the establishment of NASA, there had been a rather extensive program of sounding of the upper atmosphere in this country. The United States fired some 400 sounding rockets before the International Geophysical Year. During the 1½ years of the Geophysical Year another 200 have been launched and, of course, we also launched our first earth satellites and space probes. With these tools we plan and we intend to continue to investigate the upper atmospheres as one particular subject. We intentionally put an "s" on the word "atmosphere" because we are thinking not only of the earth's atmosphere, but, also, the atmosphere of the Sun, the atmosphere of the planets, and the atmosphere of the Moon if there turns out to be any.

One of our major interests in the atmospheres of the planets is to get a look at different types of atmospheres so that when we come back in a broader perspective to view the earth's atmosphere, we may see things that we did not see before.

THE EARTH'S ATMOSPHERE

Figure 1 reviews some of the things we know about our atmosphere as a basis for pointing up the things we don't know and want to study.

To begin with, it is customary to measure the pressure of the atmosphere, that is the force with which it pushes down on all things submersed in it, in terms of atmospheres. The sea level pressure of our atmosphere is one atmosphere. It is actually equivalent to a force of 1 ton on a square foot of area, a square foot being a square 1 foot on the side. Since the average human being has about 20 square feet of area, this means that each person is subject to about 20 tons of force due to the Earth's atmosphere.

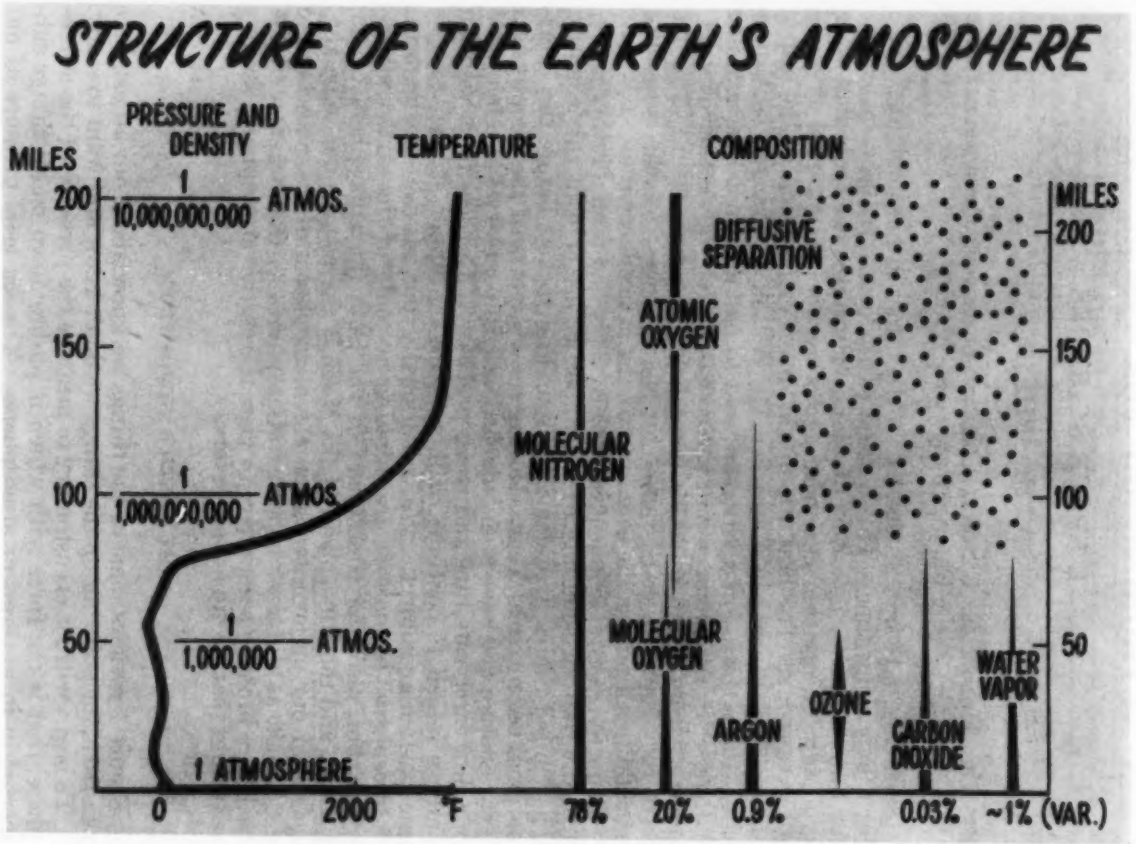

STRUCTURE OF THE EARTH'S ATMOSPHERE
PRESSURE AND DENSITY
TEMPERATURE
COMPOSITION
MILES
200
150
100
50
1/10,000,000,000 ATMOS.
1/1,000,000,000 ATMOS.
1/1,000,000 ATMOS.
1 ATMOSPHERE
0
2000
°F
MOLECULAR NITROGEN
ATOMIC OXYGEN
MOLECULAR OXYGEN
DIFFUSIVE SEPARATION
ARGON
OZONE
CARBON DIOXIDE
WATER VAPOR
78%
20%
0.9%
0.03%
~1% (VAR.)
MILES
200
150
100
50

FIGURE 1

However, when we go up to 50 or 60 miles altitude, the atmosphere has fallen off in pressure to one one-millionth of what it was at sea level, and if we go up to 100 miles the pressure has decreased to one one-billionth of what it is at sea level. So you see the atmosphere is thinning out, not just gradually, but quite rapidly as we go up in altitude.

At 200 miles our measurements indicate that we have only one ten-billionth of what we have at the surface of the Earth. This doesn't mean that this is unimportant to us even from a practical point of view, because it is in this region of the atmosphere that the ionosphere exists. This is the portion of the atmosphere which is electrified and which makes it possible for us to send radio waves around the world.

The curve represents the temperature of our atmosphere. At one time it had been thought that after the first decline in temperature which we observe as we climb mountains or as we go up in aircraft, that the temperature remains constant at about minus 70° C. But it turns out that this is not correct. The atmosphere warms up again, then cools off again, then warms up to the extremely high temperatures you see here, 2,000° to 3,000° F. This means, then, that the individual air molecules are moving about at terrific speeds and individually carry large energies in comparison with what the molecules near the ground carry. However, it does not mean that if you put a potato out here it would cook rapidly.

FIGURE 1

The reason is this: the atmosphere has thinned out so much that there aren't enough molecules to deliver sufficient heat to the potato to cook it. Rather, the potato would cool off because of the fact that it would radiate its energy, except for the side that faces the sun. The sun would heat and roast this side.

We know that the composition of the atmosphere at the surface of the Earth includes nitrogen, oxygen molecules, about nine-tenths of a percent of argon, some ozone, but not very much, and carbon dioxide. Water vapor is also present and is important as it is the major active element in our weather processes. Water vapor is highly variable. On the average it amounts to about three-tenths of 1 percent. Its maximum amount is about 2 percent.

As we go up in altitude there is not much change in nitrogen. But in the case of oxygen, a change does occur up here at 60, 70, or 80 miles. The oxygen begins to dissociate, that is to say, molecules separate into two single atoms so that at these altitudes we find atoms of oxygen instead of molecules. This is due to the effect of the sun's radiation on the upper atmosphere. Ozone is formed and reaches a maximum at 20 miles or so. The ozone molecule consists of three atoms of oxygen. It is highly lethal. In fact, seven parts per million is deadly. Up here at this altitude one finds about seven parts per million. Carbon dioxide and argon have decreased considerably, and so does water vapor.

Now we get to a region which is called the region of diffusive separation. This is just a technical way of saying it is a region in which the lighter gases drift upward and the heavier gases settle down. A common example of this is the way cream drifts upward in unhomogenized milk, and the heavier milk settles out. Thus we expect at the top of the atmosphere to find hydrogen, and down in

this portion more argon relative to, say, nitrogen than one would normally find in a well-mixed atmosphere.

You may wonder why it is that diffusive separation occurs here and not lower down. The answer is our weather, the mixing, stirring, turbulent motions of the atmosphere keep things uniform down here. When we get up here this no longer exists.

Now as to things we don't know, we don't know whether there is hydrogen up there, and we would like to find out. We will look for it. In particular, we are interested in whether or not the hydrogen joins in with a hydrogen atmosphere of the Sun. We don't understand the weather of the upper atmosphere. We are interested in learning about the effects of the Sun, the effects of geographic position and season, the nature of the winds, and so forth, for the upper atmosphere.

Now moving from this description of our atmosphere, let us consider how we make measurements of these things.

When we began the study of the Earth's upper atmosphere by using V–2 rockets right after the end of the last war, one of the first problems was to measure the variation of pressure with altitude. We had a V–2 assigned to us by the Army. It had a rigidly fixed date because of the launching problem. We didn't have any special equipment ready. The question was how to swing into action and make this pressure measurement quickly. The answer was very simple. The researcher who had this assignment simply took a small electric light bulb, knocked the top off of it, and then calibrated the base and filament as a pressure gage. The principle here was that the more atmosphere, the more rapidly the air cooled the filament of the light bulb. The less atmosphere, the less cooling, and, therefore, the higher the temperature of the filament.

The higher the temperature of the filament, the more resistance in it. The resistance could be measured in the rocket and radioed back to the ground. Thus, by measuring the varying electrical resistance of this modified light bulb at each altitude, we got our first measurements of pressure in the upper atmosphere.

From that first start to the present day, instrumentation has become more and more complicated. We now have instruments like this one in figure 2 which is capable of determining the different constituents in the atmosphere.

In this case what happens is that the atmospheric gases near the rocket are brought into the instrument. They are bombarded by electrons from a hot filament. This causes the atmospheric gases to become charged. Now charged particles moving in a magnetic field move in a curved path. The magnetic field causes the charged particles to deflect. In fact, it is this property that is used in TV tubes now for focusing the beam from the electron gun which makes your picture on the TV tube.

By varying the intensity of the magnetic field one can pick out which particle will be brought back to the detector. With such an instrument one can record a series of peaks corresponding to the individual constituents of the atmosphere. In a rocket, of course, this measurement has to be made automatically, put into a telemetering or radio transmitter, and sent to ground where it is received. A recorder then transcribes the data into a record.

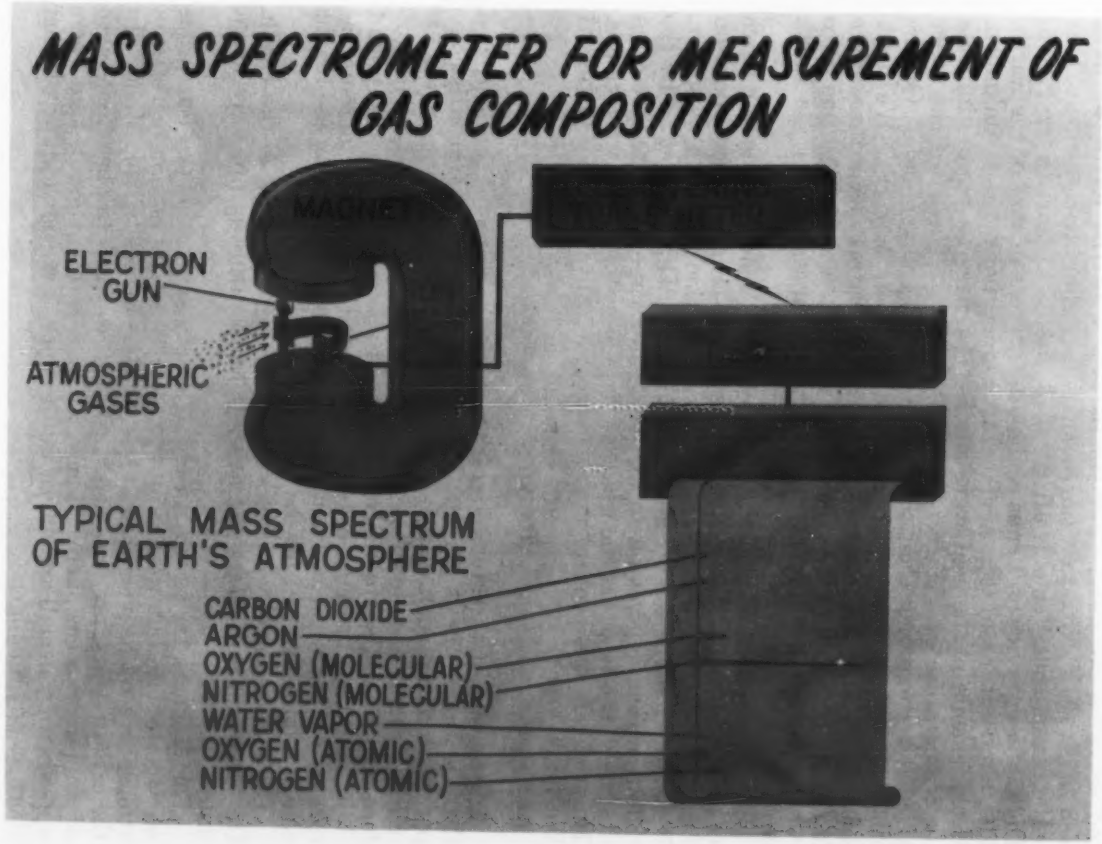

MASS SPECTROMETER FOR MEASUREMENT OF GAS COMPOSITION
MAGNET
ELECTRON GUN
ATMOSPHERIC GASES
TYPICAL MASS SPECTRUM OF EARTH'S ATMOSPHERE
CARBON DIOXIDE
ARGON
OXYGEN (MOLECULAR)
NITROGEN (MOLECULAR)
WATER VAPOR
OXYGEN (ATOMIC)
NITROGEN (ATOMIC)

FIGURE 2

This is only one of many types of instruments that are used for this sort of work.

THE ATMOSPHERE OF VENUS

Let us look beyond the Earth's atmosphere out to the other planets and see what we have. For comparison with the Earth we have Venus (fig. 3). Note that the diameters are roughly the same. This is the reason that Venus is often called the twin planet to the Earth. The surface gravity on Venus is about 85 percent of that of the Earth. The temperature of the surface of Venus, however, is unknown. Measurements in the heat wavelengths, the infrared region, indicate the temperature of Venus to be about 110° F. This is of the order of what we experience on the Earth during summer days. On the other hand, radio wave measurements indicate 570° F. We don't know just where this temperature applies, but it may be at the surface of the planet itself. If it does, then it raises serious questions as to whether any life can exist. The average temperature for the Earth is about 60° F.

The atmospheric pressure at the surface of Venus is probably twice as great as that of the Earth because there is more atmosphere on Venus. We don't really know the composition of the atmosphere. We know that there is some carbon dioxide. This is detected by the radiation that it gives off to us. No water vapor has been detected in spite of the fact that the whole surface is covered by intense clouds. Those clouds are probably carbon dioxide. Is there any nitrogen? We don't know.

THE MOON AND MARS

In the case of the Moon and Mars (fig. 4), it should be mentioned that the Moon is not a planet. It is our satellite. However, it is comparable to the planets so it is included here. The Moon is only 2,000 miles in diameter, and Mars has a diameter of 4,000 miles. The surface gravity on the Moon is one-sixth of that on Earth, so a 60-pound child would really weigh only 10 pounds on the Moon. The temperature on the Moon varies from the boiling point of water on the bright side to minus 243° F. on the dark side.

The surface gravity of Mars is about four-tenths that of the Earth. On the surface of Mars the average temperature is probably about minus 15° F.

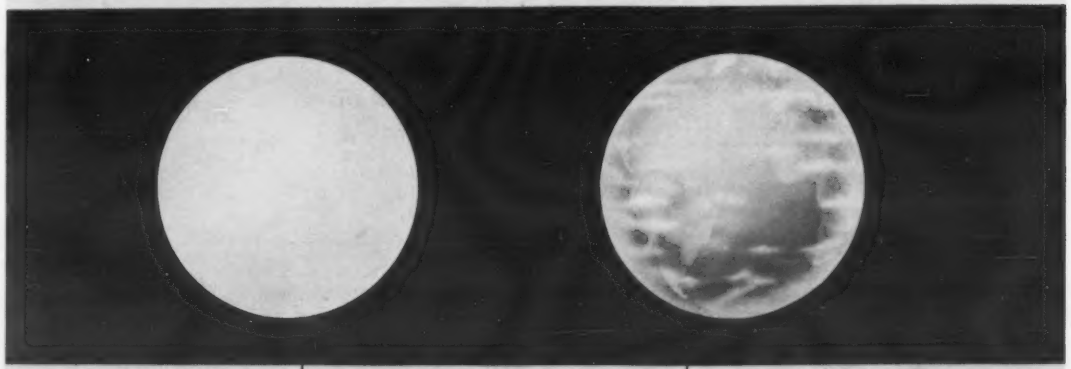
The Moon as far as we can tell from the surface of the Earth has no atmosphere, but we are interested in whether or not there is an atmosphere of heavier gases close to the surface of the Moon. In the case of Mars, pressure at the surface amounts to about one-tenth of an Earth atmosphere. There is some carbon dioxide and there appears to be a small amount of water vapor. We don't know whether there is any nitrogen.

JUPITER AND SATURN

Jupiter and Saturn (fig. 5) are most interesting planets. Jupiter is by far the largest planet, 86,000 miles in diameter. Saturn comes next, 74,000 miles. The surface gravity of Jupiter is two and a half times that of the Earth, so you would find it rather difficult to walk

53795 O—60—Pt. 2——2

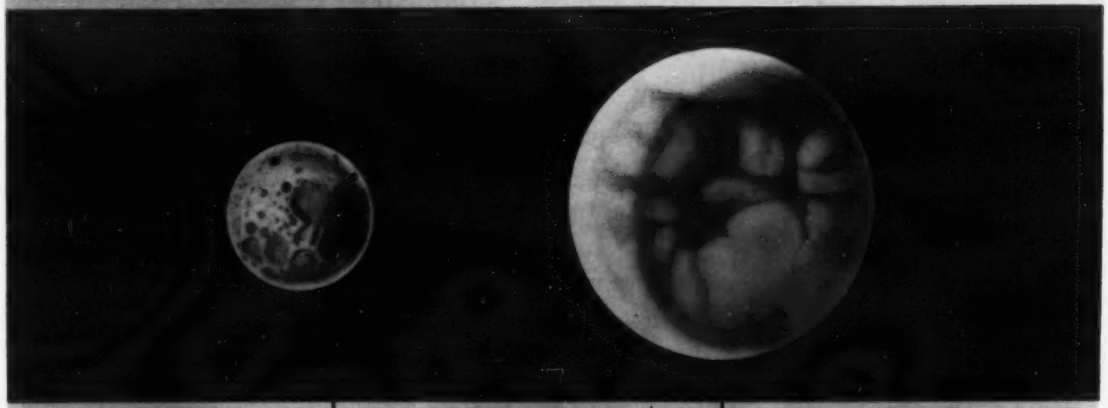
VENUS AND EARTH



PLANET	VENUS	EARTH
DIAMETER	7,800 MILES	7,920 MILES
SURFACE GRAVITY RELATIVE TO EARTH	0.85	1.0
TEMPERATURE	110°F ABOVE CLOUDS (INFRA-RED) 570°F AT SURFACE (RADIO @3.15cm)	60°F (SURFACE)
ATMOSPHERIC PRESSURE AT SURFACE	2 (?)	1
ATMOSPHERIC COMPOSITION	CARBON DIOXIDE (WATER VAPOR? NITROGEN?)	AIR { NITROGEN, OXYGEN ARGON, CARBON DIOXIDE WATER VAPOR

FIGURE 3

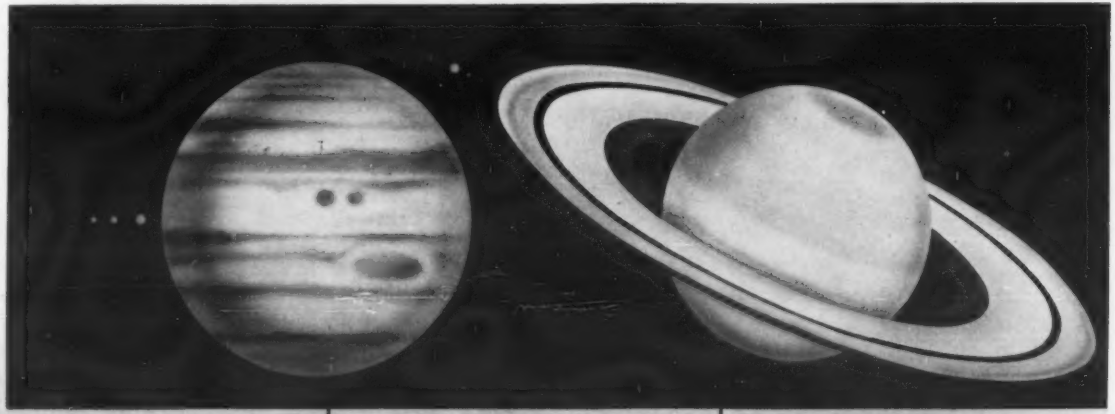
MOON AND MARS



PLANET	MOON	MARS
DIAMETER	2,162 MILES	4,215 MILES
SURFACE GRAVITY RELATIVE TO EARTH	0.16	0.38
TEMPERATURE	212°F FULL MOON (SURFACE) -243°F DARK SIDE	-15°F (SURFACE)
ATMOSPHERIC PRESSURE AT SURFACE	ESSENTIALLY ZERO	1/10
ATMOSPHERIC COMPOSITION	?	CARBON DIOXIDE WATER VAPOR (NITROGEN?)

FIGURE 4

JUPITER AND SATURN



PLANET	JUPITER	SATURN
DIAMETER	86,720 MILES	74,940 MILES
SURFACE GRAVITY RELATIVE TO EARTH	2.64	1.17
TEMPERATURE	-240°F (SURFACE)	-290°F (SURFACE)
ATMOSPHERIC PRESSURE AT SURFACE	?	?
ATMOSPHERIC COMPOSITION	AMMONIA, METHANE [HYDROGEN? NITROGEN? OXYGEN? WATER VAPOR?]	AMMONIA, METHANE HYDROGEN? NITROGEN? OXYGEN? WATER VAPOR?

FIGURE 5

around on Jupiter if you could get there. The surface gravity of Saturn is slightly more than that of the Earth.

Size doesn't necessarily determine the gravity. The total mass in the object is important in determining this. That is why Saturn, although it is nearly as large as Jupiter, has a considerably lower gravity. The temperature at the surface of minus 240° F. is quite forbidding.

In the case of Saturn, the temperature is even lower. We do not know the atmospheric pressure. This is something we would like to find out. We know that both of these planets have ammonia and methane in their atmospheres, certainly an inhospitable sort of atmosphere. In the case of Jupiter, we suspect that there is a considerable amount of hydrogen and helium. We don't know about nitrogen, oxygen, or water vapor. We have the same questions about Saturn. Of course, we are very much interested in what the rings are.

IONOSPHERES

By Dr. John F. Clark, Chief, Geophysics Programs, NASA

The Earth's ionosphere is the spherical shell of charged atmospheric gases which stretches from 40 miles to many tens of thousands of miles above the Earth. This region has been studied intensively since its discovery some four decades ago, because on its vagaries depends the very existence of all shortwave intercontinental radio communications.

The ionosphere is a part of the atmosphere, and the thing which distinguishes it from the rest of the atmosphere is that the particles which make up the gas of the ionosphere are electrically charged. Because the gas molecules are exposed to the sun's radiation, this intense radiation actually separates an electron from the rest of the molecule, and so we have the free electron which is responsible for most of the ionospheric effects, and we have the remaining part of the molecule which is now called an ion, and together these provide the charged particles that make up the ionosphere. Our knowledge of the ionosphere first came into being in the second decade of this century. Most of the work was done by Heaviside in England in which he postulated that the long-range radio communications which Marconi had observed could only be explained by the ionosphere, a conducting and reflecting layer in the Earth's upper atmosphere. This turned out to be so.

THE IONOSPHERE AS SEEN FROM THE EARTH'S SURFACE

Figure 6 shows the Earth's ionosphere as it was pictured before the advent of rockets and satellites. During daylight hours, as seen on the right side of the figure, ultraviolet rays from the sun produce maximum charging or ionization of the atmospheric gases at four particular levels: The D region at from 35 to 50 miles altitude, the E region at 60 miles, the F1 region at 120 miles, and the F2 region at some 180 miles. These charge density distributions vary with latitude, with season, and with activity on the Sun. At night, as shown on the left side of the figure, the two F regions merge, the E region becomes patchy or sporadic in nature, and the D region disappears altogether.

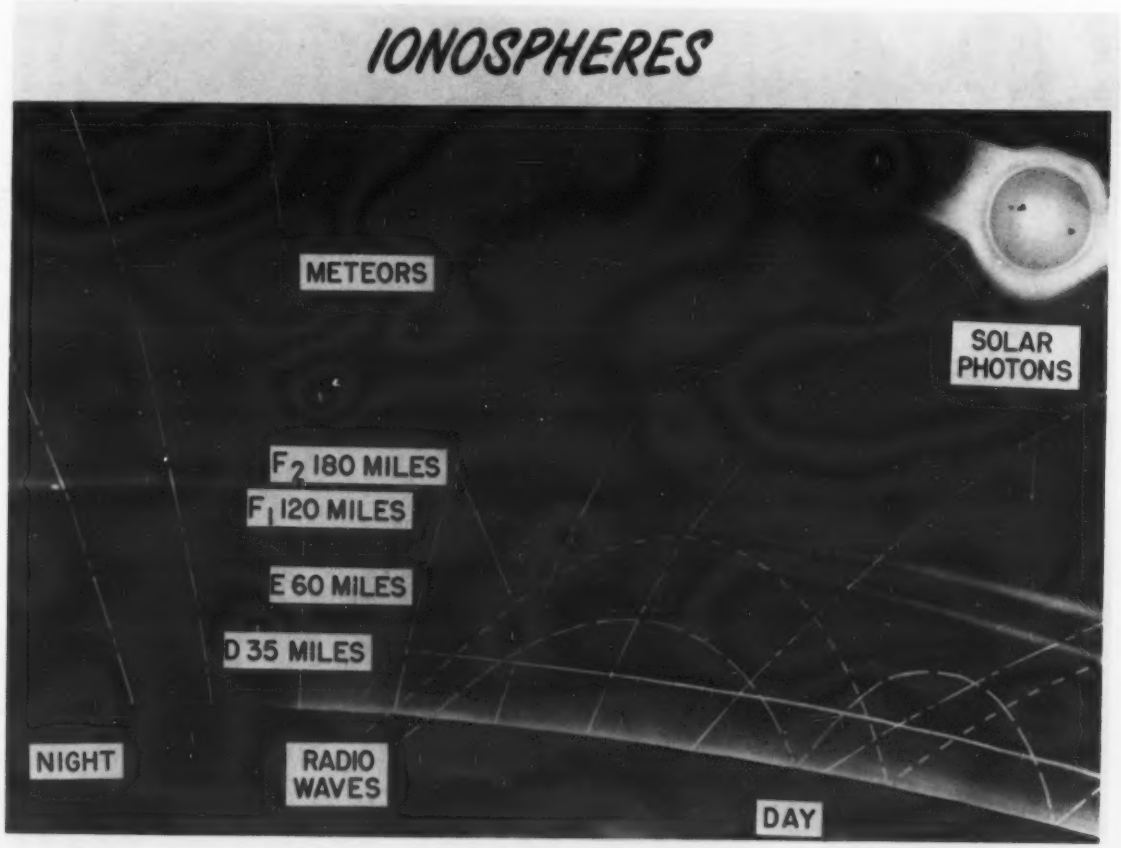

IONOSPHERES
METEORS
SOLAR PHOTONS
F_2 180 MILES
F_1 120 MILES
E 60 MILES
D 35 MILES
NIGHT
RADIO WAVES
DAY

FIGURE 6

The arctic and antarctic ionospheres are particularly subject to erratic effects which are related to auroral displays (northern lights). Such disturbed ionospheric conditions are frequently related to ionizing streams of particles which take several days to reach the Earth's atmosphere from the Sun. Meteors also make a small contribution to the charging or ionization of the atmospheric gases, particularly in the E region.

Much of the importance of the ionosphere centers on its effect on worldwide radio communications. In effect, it is possible to bounce certain radio waves off the lower surface of the ionosphere and back again to Earth thousands of miles away. In this regard, the ionosphere may be likened to an electrical sieve, or more correctly a series of sieves, extending around the Earth at the height of the ionospheric E and F regions. If the size of the mesh of the sieve which represents the E region is specified at 4 inches, then the effective mesh size of the F region must be less, say 1 inch. High radiofrequencies such as those used for television may be likened to marbles which, as shown on the chart, shoot through the ionospheric mesh into outer space, never to return. As the radiofrequency is reduced to those primarily used for short-wave communications, we find that like tennis balls, they penetrate the larger mesh of the E layer only to bound back from the F layer, thus resulting in the longer paths of communications shown on the chart. As the frequency is reduced still further, say to those of the conventional radio broadcast band, the waves may be likened to basketballs which rebound off the E region and even at night provide only relatively short communication paths. There is one more category, that of very low radiofrequencies of the type which the Navy uses to maintain worldwide contact with its ships, which may be likened to long sticks which when alined with the magnetic field lines of the Earth can penetrate the ionospheric mesh along the magnetic lines of force.

We know very little about the ionospheres of other planets. On theoretical grounds, one might expect ionospheres on the major planets. The detection of radio bursts from Jupiter and the optical indications of an aurora on Venus indicate that these planets, at least, may possess ionospheres similar in some regards to that of the Earth.

ADDITIONAL KNOWLEDGE ALREADY OBTAINED FROM ROCKETS AND SATELLITES

During the International Geophysical Year rocket flights in the Arctic disclosed the important fact that disturbed low-altitude D region ionization is due to X-rays from the Sun, in contrast to the ultraviolet radiation responsible for the normal higher altitude ionospheric charging. It is hoped that more knowledge of this phenomenon may lead to the ability to forecast these important disturbances to communications in Arctic regions. It was also learned that the ionospheric regions do not have deep "valleys" between them, but rather than the ionosphere is a connected region with only minor variations in the density of charged particles, as shown in figure 7. At altitudes above the F region maximum, the Russian rocket and satellite data disclose a rather surprisingly slow decrease in density of charged particles with altitude. The density of electrons exceeds

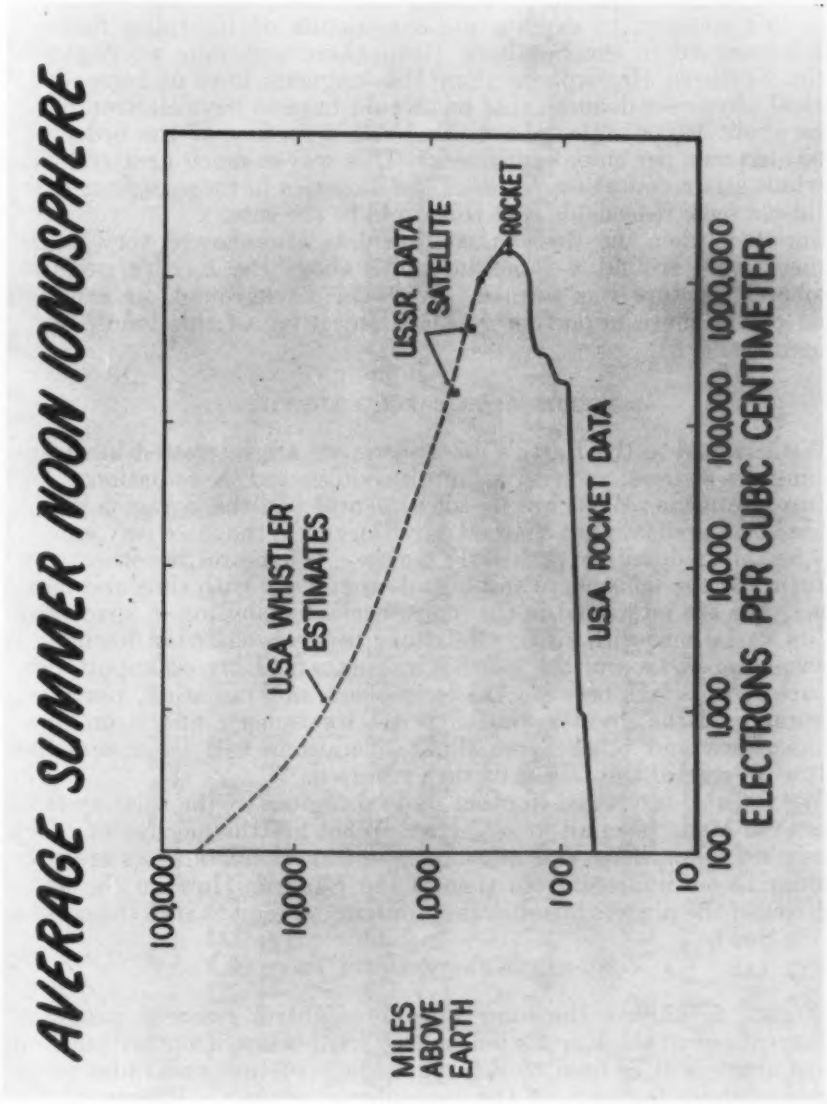

AVERAGE SUMMER NOON IONOSPHERE
MILES ABOVE EARTH
100,000
10,000
1,000
100
10
USA WHISTLER ESTIMATES
USSR DATA SATELLITE
ROCKET
USA ROCKET DATA
100
1,000
10,000
100,000
1,000,000
ELECTRONS PER CUBIC CENTIMETER

FIGURE 7

10,000 per cubic centimeter from 100 to 1,000 miles. Thus, the bulk of the ionosphere lies above the F2 region maximum, at 180 miles altitude. Consequently, the ionosphere may have a correspondingly greater influence on communications between spacecraft and the Earth than had been anticipated.

In this country, to explain radio reception of lightning flashes, which occurred in the Southern Hemisphere and were propagated to the Northern Hemisphere along the magnetic lines of force, theoretical physicists deduced that one would have to have electron densities about 10,000 miles above the Earth's surface of the order of 1,000 electrons per cubic centimeter. This was so much greater than previous astronomical estimates of the densities in these regions that it did not seem reasonable that this could be the case.

But then when the Russian satellite data also showed very much higher levels around a thousand miles above the Earth's surface, a coherent picture was formed. With this background, we can list some of the more important research objectives of this ionospheres program (fig. 8).

IONOSPHERES RESEARCH OBJECTIVES

With regard to the Earth's ionosphere, we are interested in determining its sources, such as solar ultraviolet and X-radiation. By nature, we mean: What are its constituents? In the E region nitric oxide is the predominant charged particle, and in the same way atomic oxygen is predominant in the F region. What are the other constituents of the ionosphere and how do they vary with time and location? We are interested in the ionospheric distribution in space and in its variations with time. Relations between currents flowing at ionospheric levels and the Earth's magnetic field are of importance, as are interactions between the ionosphere and radiation, particles, auroras, and the great radiation belt. Ionospheric effects on communications and other space flight operations will be understood better because of the results of such research.

We are also interested in other ionized regions of the solar system. Does the Moon have an ionosphere? What are the natures of other planetary ionospheres and in what important characteristics are they similar to or different from that of the Earth? How do the ionospheres of the planets blend at their outermost regions into the corona of the Sun?

LONG-RANGE IONOSPHERES PROGRAM

Figure 9 outlines the long-range ionospheres research program. Observations of the Earth's ionosphere from below, from within, and from above will be used to determine the structure and radio propagation characteristics of the ionospheric regions. Effects of the ionosphere on space flight operations and communications will be evaluated. Using the knowledge thus gained, other planetary ionospheres will be investigated, first from above, and later, as space probes come closer to other planets, from within. Such flights will provide an excellent opportunity to evaluate the effects of ionized regions in interplanetary space on space communications.

IONOSPHERES RESEARCH OBJECTIVES

EARTH'S IONOSPHERE

- SOURCES AND NATURE
- DISTRIBUTION IN SPACE
- VARIATIONS WITH TIME
- ATMOSPHERIC CURRENTS AND MAGNETIC FIELD
- INTERACTIONS WITH RADIATION AND PARTICLES
- AURORAS AND GREAT RADIATION BELT
- COMMUNICATIONS AND SPACE FLIGHT OPERATIONS

OTHER IONIZED REGIONS

- MOON'S IONOSPHERE
- PLANETARY IONOSPHERES
- SOLAR CORONA

FIGURE 8

LONG RANGE IONOSPHERES PROGRAM

EARTH'S IONOSPHERE

OBSERVATIONS BELOW, WITHIN, ABOVE
STRUCTURE, PROPAGATION CHARACTERISTICS
EFFECTS ON SPACE FLIGHT

PLANETARY IONOSPHERES

OBSERVATIONS ABOVE, WITHIN
EFFECTS ON SPACE COMMUNICATION

PROPAGATION OBSERVATORY ON MOON

COSMIC NOISE
PROPAGATION THROUGH EARTH'S IONOSPHERE

FIGURE 9

The advisability of establishing a propagation observatory on the Moon is also under consideration. Such an observatory would be useful to monitor the cosmic noise which forms the background for interplanetary communications, and to investigate one-way propagation through the Earth's ionosphere on a continuing basis. A lunar relay station may also be necessary in the event that very low frequencies, which will not propagate readily through the ionosphere, are used for interplanetary communication.

SHORT-RANGE IONOSPHERES PROGRAM

Figure 10 lists the important components of the short-range ionospheres research program. The structure of the ionized regions above 200 miles will be investigated by means of propagation through this medium, by means of direct measurements in the vicinity of satellites and space probes, and by radio sounding from below and from above the ionosphere. Particular attention will be paid to the variations of the density and composition of these regions with time, with season, with latitude, and with activity on the Sun. Very low frequency propagation through the ionosphere will be investigated, with a view toward the use of possible "windows" through the ionosphere at these frequencies for future interplanetary communications. Cosmic radio frequency noise will be studied in the outer ionosphere, at frequencies which do not penetrate through the F region to the Earth's surface. The results of such measurements will be useful in research on processes in outer space which cause these radiations, as well as in basic communication studies for which this cosmic noise may be the limiting factor in determining appropriate frequencies for interplanetary communications.

Interactions between the charged particles in the ionosphere and spacecraft will be measured, both to gain additional important data regarding the ionosphere in the region around the spacecraft, and to evaluate effects produced by such interactions on electrical measurements made from the surface of the spacecraft. Another important aspect of such measurements has to do with the increase in effective cross sections of the charged vehicle to charged particles, since like charges repel and unlike charges attract. Under certain circumstances, such electrical drag effects could cause appreciable trajectory errors.

THE IONOSPHERIC TOPSIDE SOUNDER

The equipment which is used in making these various measurements of ionospheric characteristics consists mostly of conventional miniaturized and transistorized radio receivers and transmitters. Figure 11 illustrates a particularly interesting example of such techniques in diagrammatic form. For a number of years ground-based ionospheric radio sounding stations have determined the heights of the ionospheric E and F regions by means of short radio pulses which bounce from the ionosphere, as shown on the lower left corner of the chart, and are received at the same ground station later in time, by an amount which is dependent upon the height of the ionosphere. The topside sounder is an adaptation of this method for use with Earth satellites. A trigger pulse from the ground station at a radio frequency sufficiently high

SHORT RANGE IONOSPHERES PROGRAM

IONOSPHERIC STRUCTURE ABOVE 200 MILES

VERY LOW FREQUENCY IONOSPHERIC PROPAGATION

COSMIC NOISE IN THE OUTER IONOSPHERE

INTERACTIONS BETWEEN CHARGED PARTICLES AND SPACECRAFT

FIGURE 10

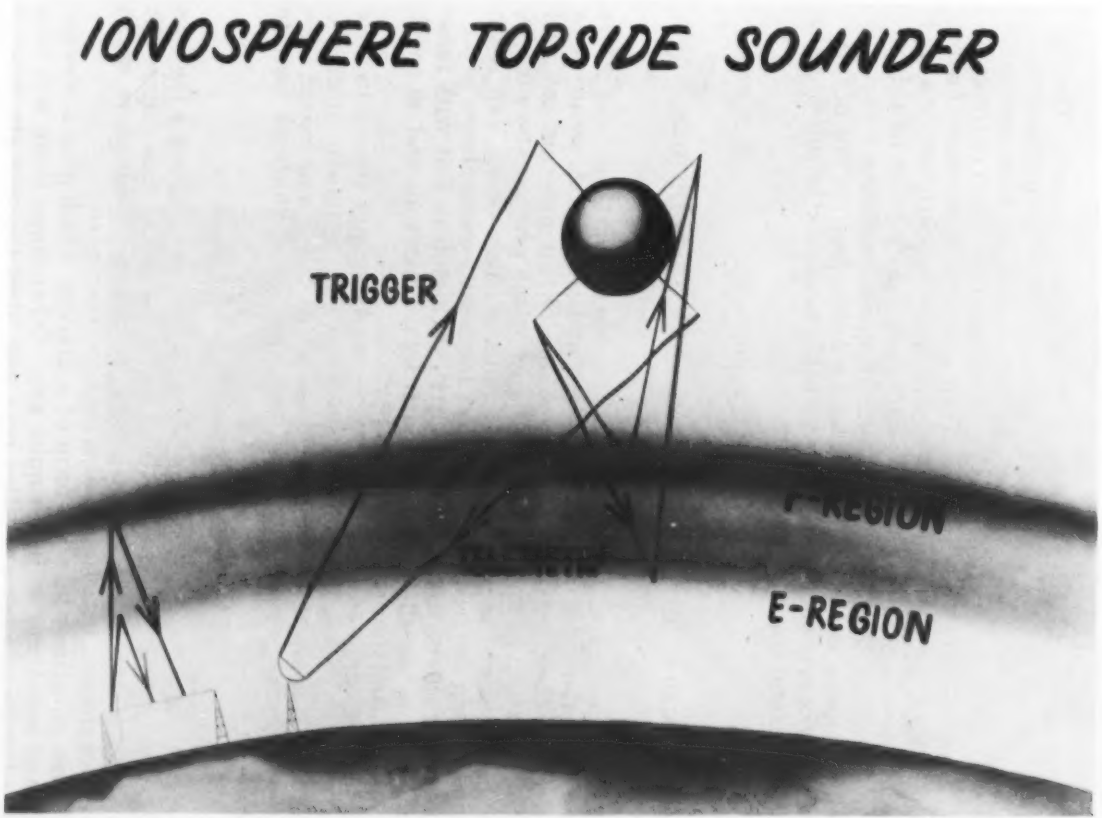


FIGURE 11

to penetrate the ionosphere causes a lower frequency pulse to be transmitted from the satellite. This pulse is in turn reflected back to the satellite from the various ionospheric regions, and subsequently telemetered to the ground station. In this manner a simultaneous indication can be obtained of the ionospheric characteristics from below and from above.

This experiment is also of interest from another aspect. The Canadians are particularly interested in arctic ionospheric characteristics, because of their unusual radio communication problem associated with the presence of the disturbed auroral zone over much of the country. Consequently, they are contributing some 20 man-years of effort to the design, development, and construction of rocket, satellite, and ground-based equipment for the swept-frequency version of this experiment. The United States is providing the sounding rocket and satellite booster systems. This is both a most effective type of international cooperation, and a highly valuable means for broadening the base of the total space research effort.

ENERGETIC PARTICLES

By Dr. Leslie H. Meredith, Chief, Space Sciences Division, NASA Goddard Space Flight Center

The subject of this section is the energetic particles which are present in the space around the earth, and the NASA program to investigate these particles. More specifically this program is aimed at investigating cosmic rays, the particles which produce the auroras, the particles which form the great radiation belt which Van Allen found during the past year, and then for these various classes of particles their interactions with the Earth's atmosphere and with other atmospheres, the effects of these particles on materials and on living organisms, and the origins of these particles.

For ease in discussing these particles we have split them into these three general classes. There are, however, undoubtedly interrelationships between the particles of these three classes, and indeed these interrelationships are one of the many problems which we have to look into.

AURORAS

Of these three classes of particles, the auroral particles are the ones which man has observed for the longest period of time, figure 12. It is the impact of these particles on the Earth's atmosphere which produce auroras, sometimes called the northern lights.

These sometimes take the form of a drapery which goes across the sky and sometimes as just a quiet arc. Other times there will be a large bundle of what are called rays, and when the rays are straight overhead they may appear like the corona shown on the chart. The aurora can change from one of these forms to a different form very rapidly, and this is one of the questions as to just exactly why this happens.

They can also be very faint and then very suddenly increase markedly in intensity. The faintest auroras are about as bright as the milky way and some of the brightest ones give as much light as a full Moon. About the start of this century ground based measure-

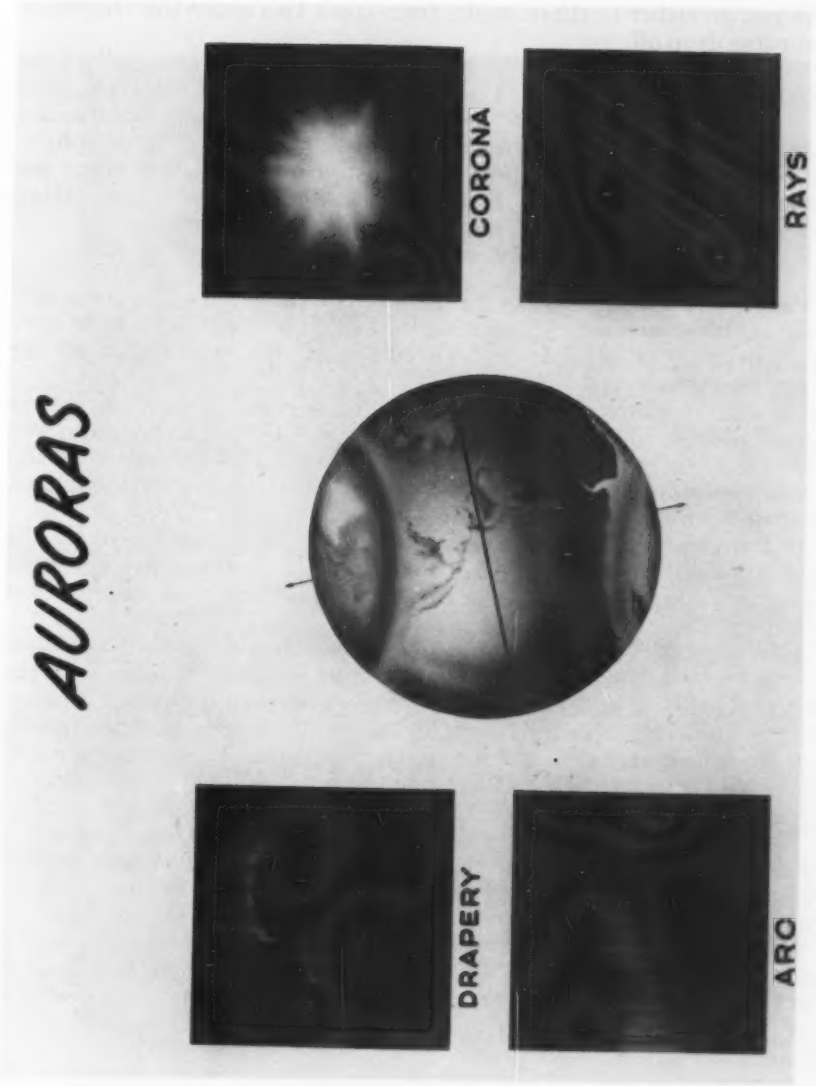


FIGURE 12

ments showed that there were two regions on the Earth in which auroras could be seen almost every clear night. These two zones are shown as arcs on the globe (fig. 12).

As you go either north or south from these two zones the frequency of auroras drop off.

It was not until recently, however, that rockets were actually fired into these visible auroras. These were fired as part of the IGY from Fort Churchill in Canada. These rockets showed that auroras are produced by electrons incident on the Earth's upper atmosphere. This is just a start of the program because we found that there are also protons incident on the atmosphere and many other complicating features.

COSMIC RAYS

About at the start of this century it was found that there were also other particles incident on the atmosphere. These particles have very high energy and indeed produce effects all the way down to the Earth's surface.

Since their discovery these particles called cosmic rays have been measured from deep mine shafts to far out into space and from one pole of the Earth to the other. As a result of all these measurements, it has been found that these cosmic rays are coming to the Earth uniformly from all directions (fig. 13).

At the Equator the Earth's magnetic field, which is shown by the light lines on the chart, bends these particles so that only the high energy ones can reach down to the Earth, and the lower energy ones are thrown out.

As you go either north or south, however, the particles do not have to cross so much of the magnetic field, and at the poles all of the particles can get in, both the high energy ones and the low energy ones, as they don't have to cross the field at all. By measuring this change in the intensity of these particles with latitude, and by many other means, we have been able to find out what the energy spectrum of these particles is, and figure 14 shows what we have found.

This doesn't mean that this is a firm curve. There are many questions as to exactly what the spectra is in this low-energy region, and this is one of the things that our program is aimed at. Also, the spectrum is known to vary.

From this curve, however, it can be seen that the cosmic rays have a very high energy. At the end of the curve you have 1 million billion electron volts. As a point of reference, the highest energy a particle accelerator which is on this Earth can accelerate particles to is about 10 to 15 billion electron volts.

While the individual particle energies are very high, the intensity of these particles is very low, and the total energy brought to the Earth by these particles is of the order of energy brought by starlight. The particles themselves are the nuclei of atoms. About 90 percent of the cosmic rays are protons or the nuclei of hydrogen atoms. Most of the remaining 10 percent are the nuclei of helium atoms. The 1 or 2 percent that are left are the nuclei of heavier atoms such as carbon, oxygen, calcium, and all the way out to iron.

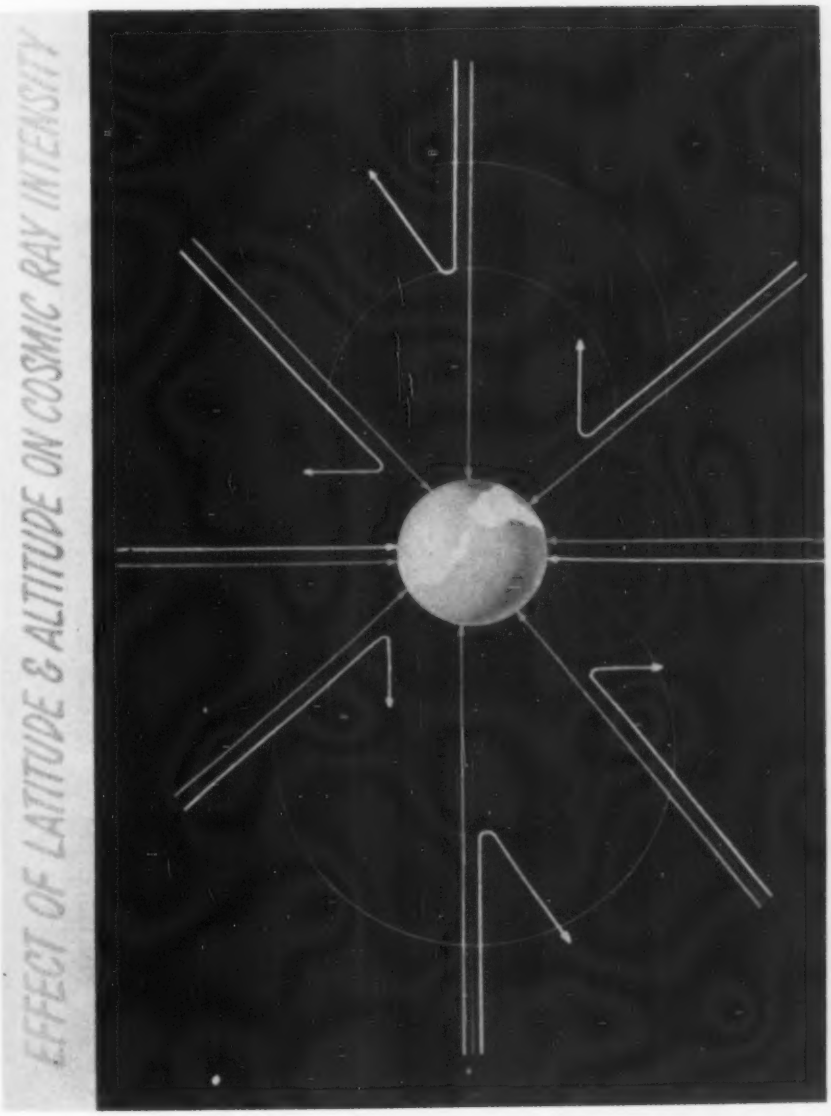


FIGURE 13

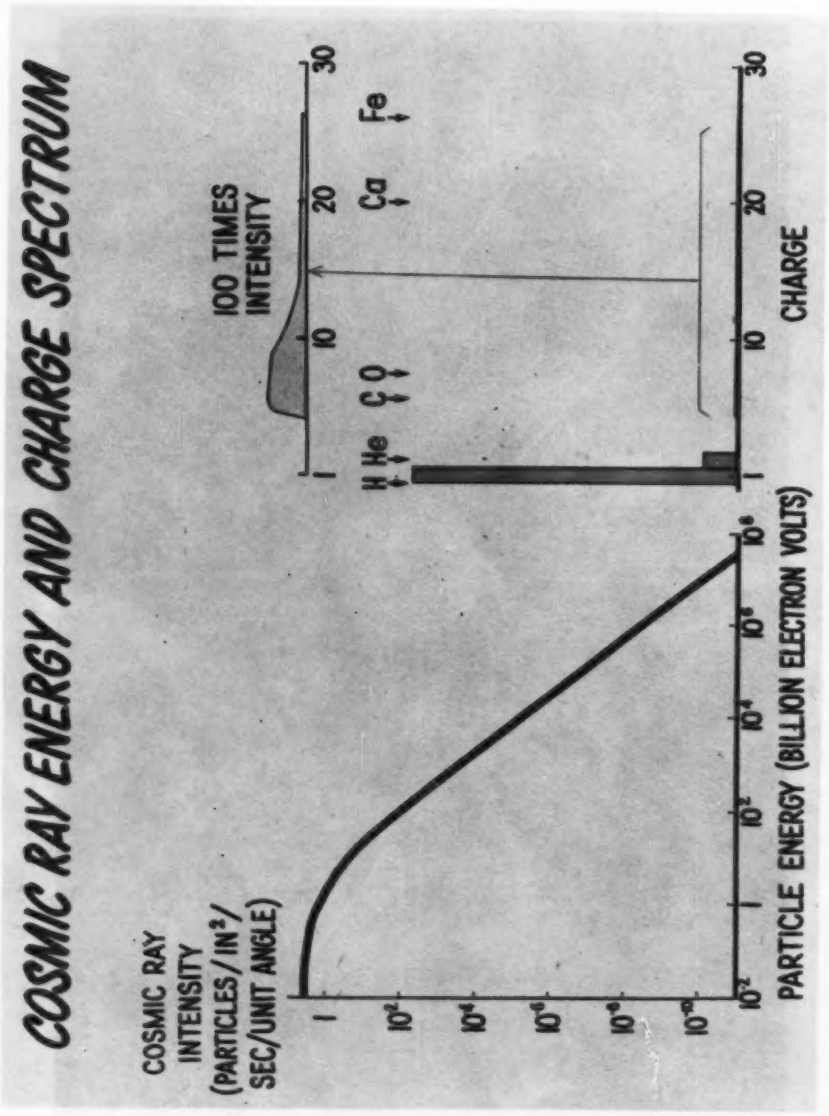

COSMIC RAY ENERGY AND CHARGE SPECTRUM
COSMIC RAY INTENSITY (PARTICLES/IN²/SEC/UNIT ANGLE)
1
10⁻²
10⁻⁴
10⁻⁶
10⁻⁸
10⁻¹⁰
10⁻²
1
10²
10⁴
10⁶
10⁸
PARTICLE ENERGY (BILLION ELECTRON VOLTS)
100 TIMES INTENSITY
H He
C O
Ca
Fe
1
10
20
30
CHARGE

FIGURE 14

RADIATION BELT

The most recently discovered of these energetic particles are those which form the radiation belt. Figure 15 gives a schematic picture of what the belt is. We don't really know yet in any detail exactly what the shape of the belt is. Nor do we know what kind of particles there are in these belts. The belt itself is a doughnut-shaped ring which goes around the earth.

What we do know is that the intensity of the particles in these regions is something about 10,000 times as high as what the cosmic ray particle intensity is, and they are undoubtedly lower energy particles than the cosmic ray particles. It is very likely that the particles in this belt have a very direct relationship to the particles which produce the northern and southern lights which would occur here on the Earth.

There are many questions which remain to be answered as to just what this radiation belt is.

FIELDS

By Dr. Robert F. Fellows, Assistant Chief, Geophysics Programs, NASA

It is very intriguing to realize that although we live in a world of physical phenomena which are governed by fields, scientists have very little realization of the true nature of a field.

A field is usually described by the effect it produces and we are all familiar with the use of magnetic fields in the generation of current, the use of a compass in the Earth's magnetic field for navigational purposes, and the effect of the Earth's gravitational field on climbing stairways. It is, for example, much harder, and we put more work into climbing stairs than we do when coming down them.

Fields are important to us for very many practical reasons. In addition, we are all interested in learning more about the fundamental nature of fields.

One very practical observation is that fields actually control the motion of all free particles, whether it be the tiniest electron, a body like an apple falling to the Earth, the Moon in its orbit around the Earth, all the planets orbiting in solar systems, and even the galaxies; all of these are controlled by laws describing behavior in fields.

THE EARTH'S MAGNETIC FIELD

The first field to explain in some detail is the Earth's magnetic field (fig. 16).

About 10° or 11° inclined from the axis of rotation we have another axis, the magnetic axis. Scientists often describe the Earth's magnetic field by imagining a bar magnet to be located in the center of the Earth. In this case the magnetic lines would travel between the north and south magnetic poles and describe closed loops, going on and on into the far distance and becoming infinitesimal in strength.

This magnetic field is not constant. It undergoes a number of types of changes. One of these changes is one occurring over periods of

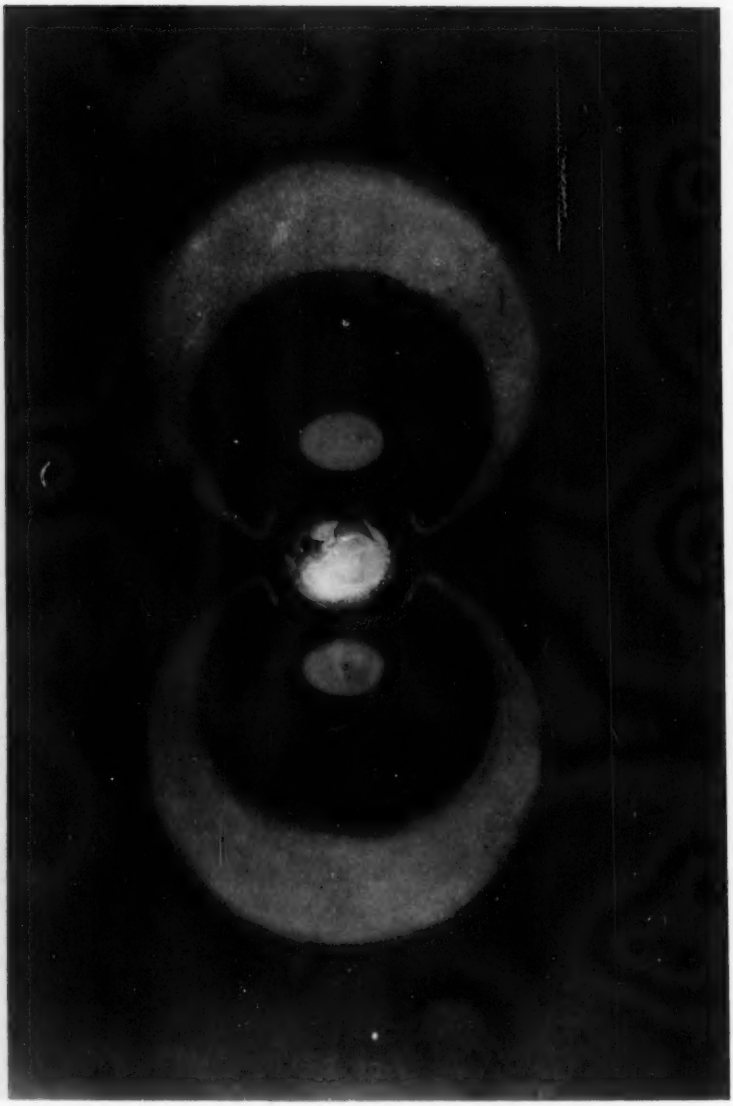


FIGURE 15

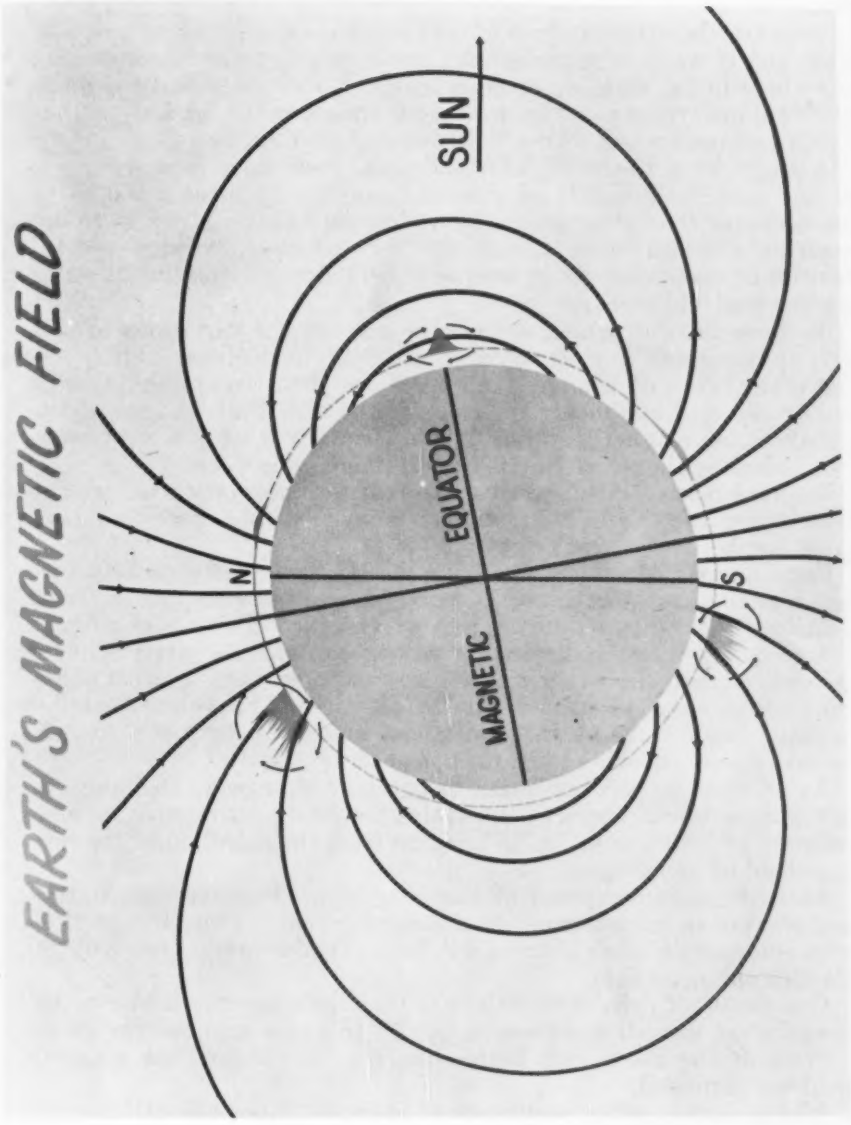


FIGURE 16

roughly months to years. This change, a rather slow progressive change that moves back and forth over the course of a century or so, is one that necessitates revision of all of our navigational charts about every 5 years to bring the charts up to date with the latest magnetic data.

There are also other changes of very much shorter cyclic nature that occur, and if we were to make very sensitive magnetic measurements somewhere in the middle northern latitudes, we would find the magnetic field undergoes very slight changes from day to night, an oscillation or variation which varies with our day-to-night cycle.

If we go down to the Equator and make these same measurements, we find that the intensity of these variations may be as much as 10 times greater than they are in the middle latitudes. If we go to the extreme latitudes where aurora are very common, we find the intensities of these changes in magnetic field strength may be as much as a hundredfold higher.

We have theories which describe or account for variations of this type as being due to electric currents in the ionosphere. There are also other types of changes, and these are more irregular, perhaps more prolonged at times. We refer to these as either magnetic disturbances, or magnetic storms. If occurrence is over a very wide area including the entire Earth, we call it magnetic storm.

We have reason to believe that these disturbances or storms are due to electric currents and interactions which are taking place outside of our ionosphere.

For a number of years and during the IGY especially, rockets were sent into the ionosphere and the atmosphere at a variety of locations including the Equator and regions of auroras. These rockets gave scientific data which indicated the presence of electric currents in the ionosphere, but the experiments also indicated that a great many more measurements were necessary before we would have sufficient data to really begin to think in detail about an explanation or a comprehensive theory covering these phenomena.

As an example of what might bring about changes in the magnetic field of the Earth (fig. 17) illustrates the Earth again with its magnetic field. Coming in, let us imagine from the direction of the Sun, is a cloud of ionized gas.

Ionized gas is composed of particles which bear electric charges, and charges in motion generate a magnetic field. Thus, the particles with their own electric charges will have certain interactions with the Earth's magnetic field.

One result of these interactions is that the magnetic field may undergo what we call a compression. In this case an observer on the surface of the Earth will notice that the intensity of the magnetic field has increased.

Under certain other conditions of energies, types of particles, and so forth, the particles may be captured: that is, they may be trapped by the magnetic lines of force of the Earth's magnetic field. This may result in changes in intensity and, in the particular case shown in figure 18, the weakening of the magnetic field of the Earth at the Earth's surface.

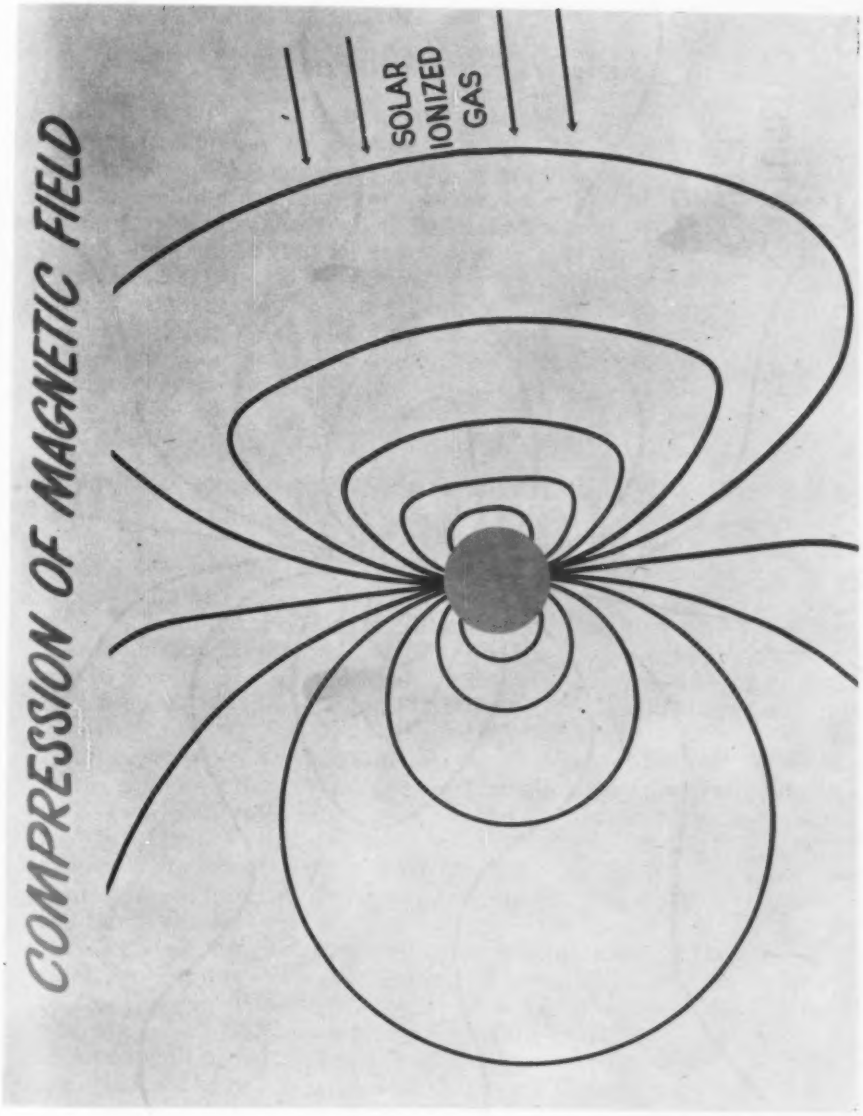


FIGURE 17

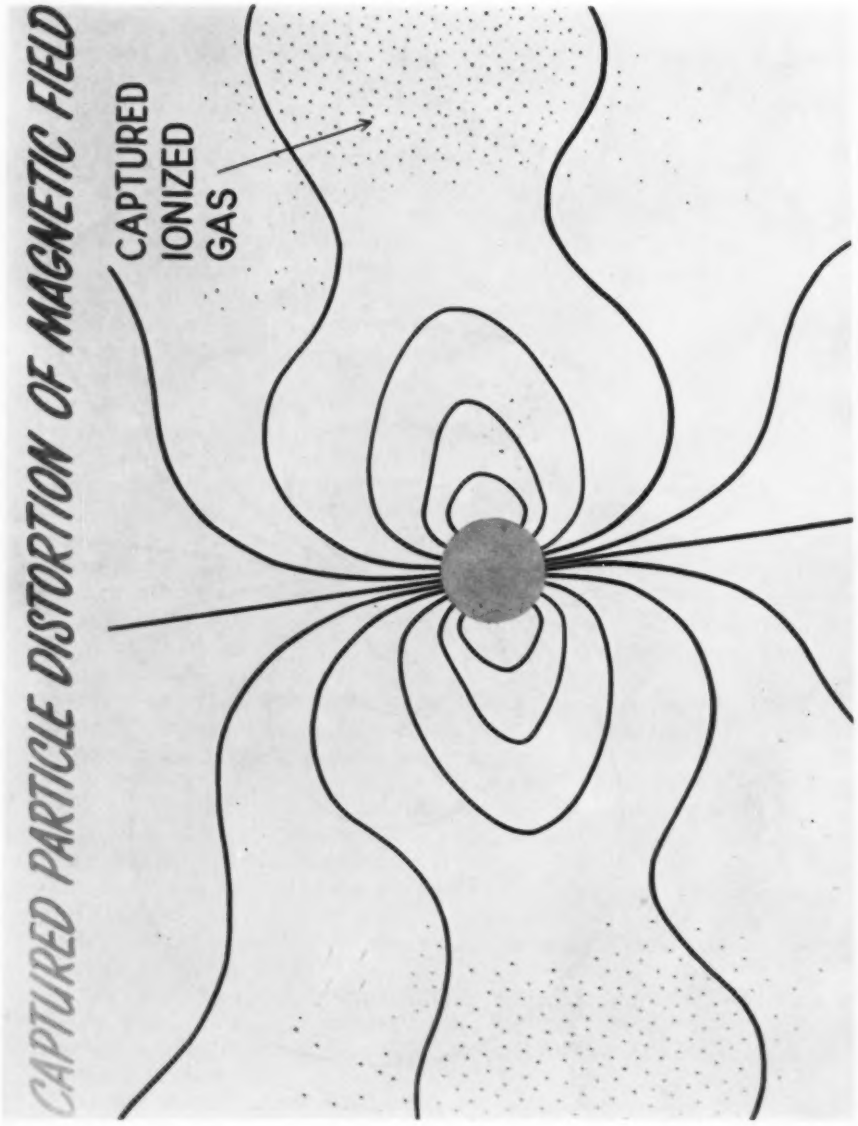

CAPTURED PARTICLE DISTORTION OF MAGNETIC FIELD
CAPTURED
IONIZED
GAS

FIGURE 18

Under certain conditions these particles are trapped for appreciable lengths of time; they will oscillate back and forth in the Earth's magnetic field. This could set up pulsations, small variations of a cyclic nature, occurring at the surface of the Earth. We have indeed observed such variations, but we do not have sufficient information at this time to be certain as to their cause.

MAGNETIC FIELDS IN SPACE

We have no factual data at this time about the interplanetary field. Figure 19 showing the planetary bodies, indicates that we know the Earth has a field; we don't know whether Venus and Mercury have fields; we know the Sun has a magnetic field and that it varies and undergoes disturbances which can be correlated with the appearance of sun spots and bursts of solar energy. We don't know whether we have an intergalactic field; we suspect so, but estimates of the intensities of this field vary by over a million. So the chart points out that we have a great wealth of opportunity available in studying the fields surrounding our planet and the other planetary bodies in space, and the interplanetary field itself.

GRAVITATION

To cover the last field, the gravitational field, we go back far into history. One of the big advances of science was when the theory of Aristotle that the Earth was the center of the universe was finally overthrown by a number of scientists including Copernicus, Newton, Galileo, and Keppler. These were scientists who made painstaking observations of the planetary bodies and their times of appearance. They tabulated their data, tried to fit laws to it or to find laws that would account for the motions of these planetary bodies, and eventually they worked out the mathematical laws which described planetary behavior.

Thus, scientists worked out the laws that accounted for the behavior of the planets. Now these laws say that the orbits for these planetary bodies will generally be ellipses. For a small manmade satellite such as one of the Vanguard satellites that ellipse should be a perfect ellipse. However, nature isn't perfect, the Earth isn't perfectly round, its surface isn't perfectly smooth, and the mass distribution of the Earth varies.

Now, these irregularities will cause irregularities in the orbit of the satellite. By very precise tracking of the satellite and the tabulation of the irregularities in the orbit of a satellite, we obtain data for making calculations concerning the Earth itself.

As a result of calculations from the Vanguard satellite 1958 Beta we find that we have a new idea of the Earth's shape (fig. 20). The old one imagines it to bulge at the Equator a little more than it actually does. The older figure is marked on the left in figure 20, and you can see it is flatter around the middle than it is for what we now consider to be the more valid shape.

Other very minor differences and irregularities which occur in the orbit of the satellite enabled us to make calculations which also indicated that the Earth is very slightly pear shaped. We are discussing

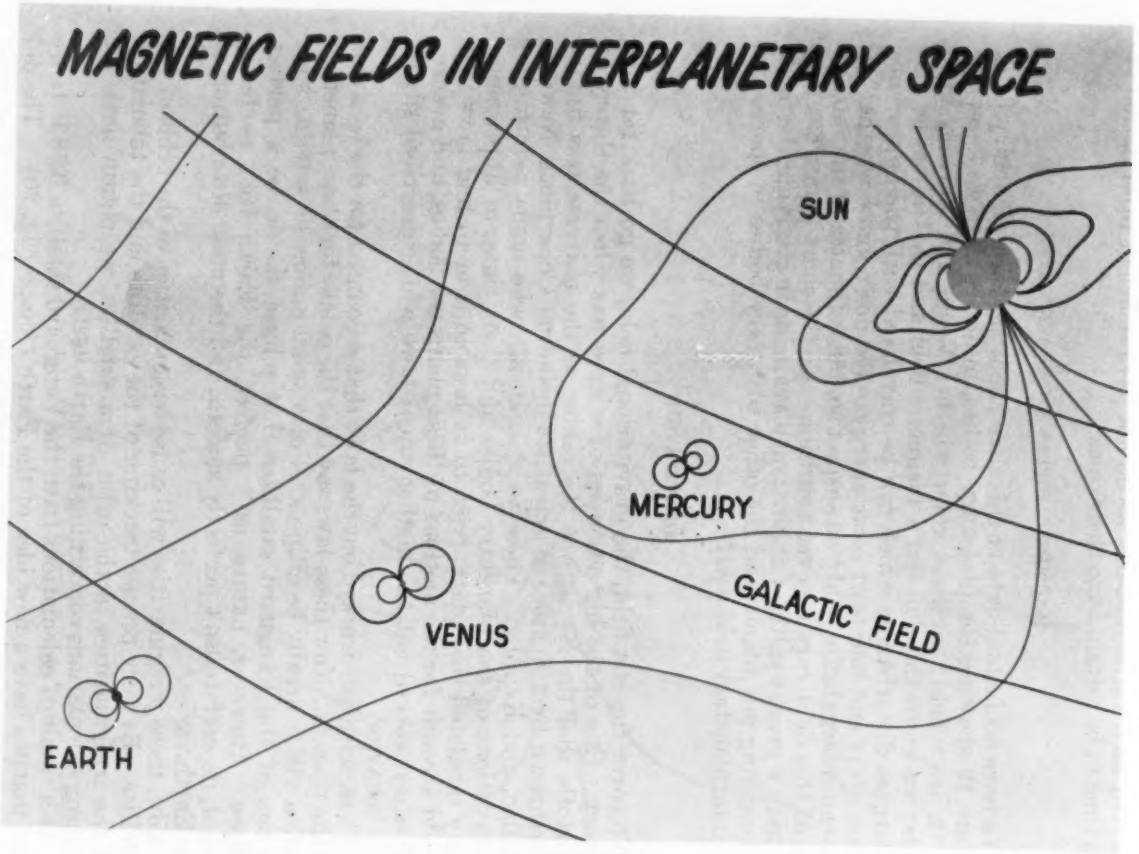

MAGNETIC FIELDS IN INTERPLANETARY SPACE
SUN
MERCURY
VENUS
GALACTIC FIELD
EARTH

FIGURE 19

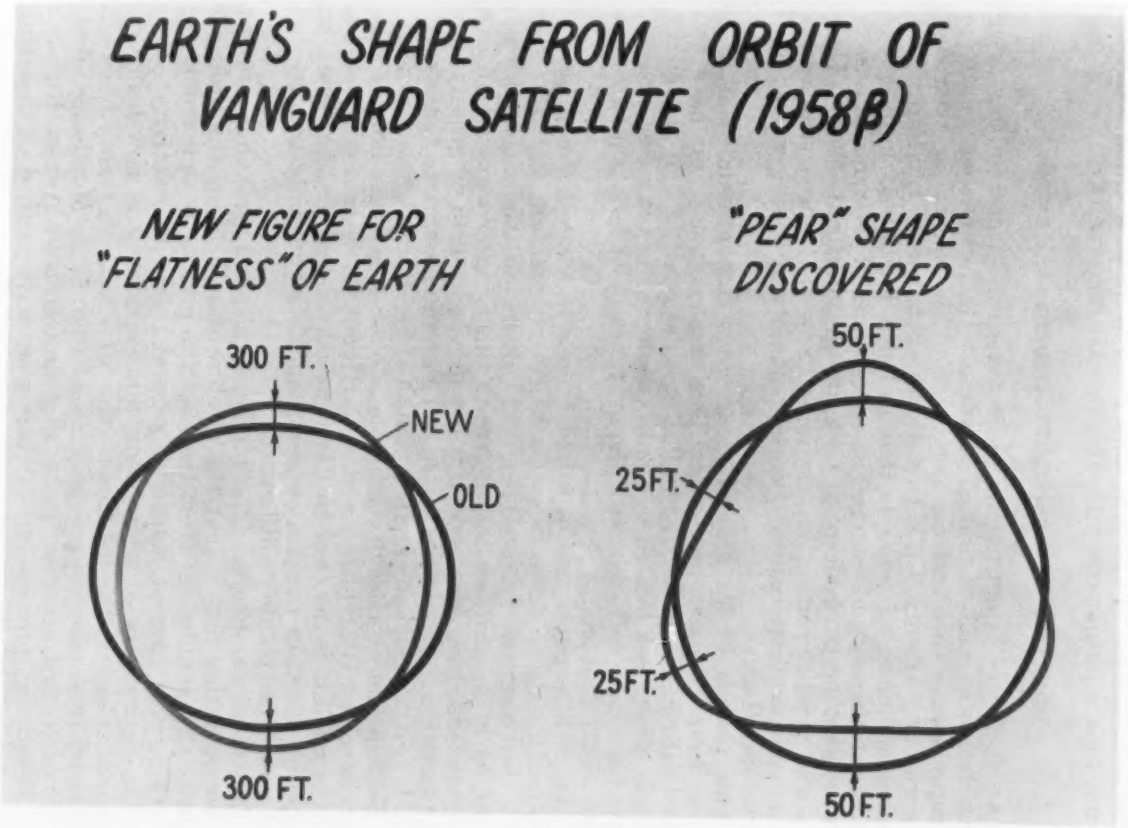

EARTH'S SHAPE FROM ORBIT OF VANGUARD SATELLITE (1958β)
NEW FIGURE FOR "FLATNESS" OF EARTH
300 FT.
NEW
OLD
300 FT.
"PEAR" SHAPE DISCOVERED
50 FT.
25 FT.
25 FT.
50 FT.

FIGURE 20

here a distance of 50 feet or so while the Earth's diameter is roughly 8,000 miles. Note also that the sides are pulled in slightly.

The main reason for including this case was to use it as an example of pointing out how very small variations are important scientifically. The accumulation of sufficient data leads to theories which better account for the phenomena with which we are concerned.

THEORIES OF EINSTEIN RELATED TO GRAVITATION

Another very famous name connected with science and involving gravitation as well, is that of Einstein. He formulated some very comprehensive theories; the general, and the special or restricted, theories of relativity. What he did in effect was to try to draw together a number of concepts that included velocity at high speeds, accelerations, mass of material objects, frames of reference of one object to another, our concept of time, and gravitational effects. These theories predict certain interactions. Now that space vehicles are attainable, we have one excellent opportunity of testing a portion of Einstein's theory.

One portion of his general theory says that gravitational fields slow down physical processes. This means that if we have two identical clocks, one located in the gravitational field of the Earth, and another clock located in a much weaker or gravity-free position, that the clocks will indicate different times if we let them run for a sufficiently long time.

We plan to put a special kind of clock in a satellite and have it telemeter its time down to an earth receiving station (fig. 21). We will then compare the satellite clock with an identical clock which is running in an earth station the entire time. After a period of time the satellite clock, by virtue of being in a lesser field of gravity than the earth clock, should run faster and gain time compared to the earth clock. So we stand an excellent chance of verifying Einstein's theory.

No experiment really is a simple one when you get down to the details of it. We realize we must watch out for certain other effects. If the satellite is too close to Earth we may actually end up with an opposite effect, or the two opposing effects may counterbalance and we would then obtain no difference.

But these are details. The fundamental point we know we must observe in this test is that the satellite should be of the order of 4,000 or 5,000 miles out from the Earth to give us an opportunity of checking this part of Einstein's general theory of relativity.

The desirability of performing this experiment is now being reviewed. Confirmation of this portion of Einstein's theory has been obtained from laboratory experiments based on the Mossbauer effect. This effect, first described in 1958 by the German physicist, Rudolph L. Mossbauer, provides an extremely sensitive method of detecting the effect of gravity on light and other radiation. In the fall of 1959 a method of using the Mossbauer effect to check this prediction of Einstein was proposed by Profs. Robert V. Pound and Glen A. Rebka, Jr., of Harvard University. Early in 1960, scientists at Harwell, the British Atomic Energy Research Establishment, reported success from experiments along these lines. Their data did, however, reflect some uncertainty. In April, Professors Pound and Rebka re-

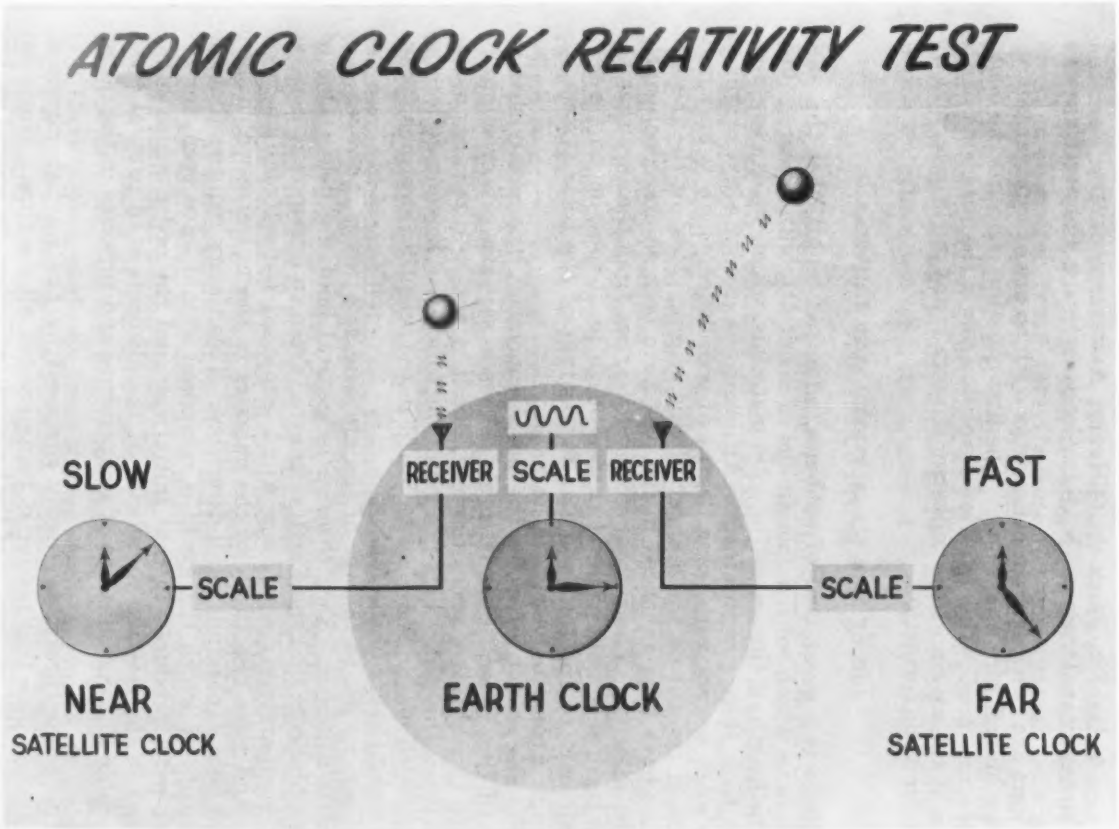

ATOMIC CLOCK RELATIVITY TEST
SLOW
RECEIVER
SCALE
RECEIVER
FAST
SCALE
SCALE
NEAR
SATELLITE CLOCK
EARTH CLOCK
FAR
SATELLITE CLOCK

FIGURE 21

ported positive confirmation from experiments in which the disturbing effects of minute differences in temperature were fully taken into account.

ASTRONOMY

By Dr. John A. O'Keefe, Assistant Chief,
Theoretical Division, NASA, Goddard Space Flight Center

There are two astronomical questions which are of especial interest to the human race as a whole. The first question concerns the origin of the universe. This question revolves around the problems of the time of the origin of the universe, if there is any such time, and the manner of its formation.

AGE OF THE SOLAR SYSTEM AND UNIVERSE

There is a great deal of evidence, admitted by all, that the solar system in which we live has an age of about 4½ billion years. This is the length of time since the solid materials, which we can examine, first took their present form. Although we can date the origin of the solar system with some degree of confidence, there is no agreement at present on the manner of this origin. Most of the theories which have been advanced in the past have been shown conclusively to be in error. The primary difficulty arises from the fact that the Sun turns much more slowly than it ought to; it contains only a very small part of the total angular momentum of the solar system, although it contains nearly all the mass.

For the galaxy, of which the sun is a member, it is certain that an age of this general class is right; that is to say, the galaxy might be twice this old or 3 times this old, but it is not 10 times this old or 100 times this old. This is a point on which our Russian colleagues agree with us and they can be heard in the scientific meetings speaking about the age of the galaxy.

When we get to the age of the universe as a whole, however, it is a little different. Two theories in general hold the field. One of these proposes that the Earth originated from an enormously massive but comparatively small egg which exploded some 10 billion years ago and gave rise to all of the galaxies in the universe which have since been expanding in all directions. This theory requires that the elements of which the world is composed should have been, for the most part, produced in that initial egg and the order which is observed in the relative abundance of the elements is in part, at least, traceable to the conditions of temperature and pressure in the initial egg.

The other theory, originally proposed by the English physicist, Hoyle, suppose that matter is being created all the time. Hoyle believes that the expansion of the universe, which we see around us, has always been going on and that in the course of time the nebulae are carried away so rapidly, that at last, we are no longer able to see them. He believes that they are replaced by new galaxies which gradually form from hydrogen which is, he thinks, constantly created atom by atom in outer space. Hoyle and his supporters see the distribution of the abundance of the elements as the result of a cooking

process which goes on partly in the interiors of the stars and partly in the collapse process of supernovae.

A decision between these two hypotheses is being sought at the present time by astronomers in a wide variety of ways; in studies of the relative abundance of elements in the sun, the stars, and the nebulae; in comparisons of the chemical compositions of stars in various clusters to try to trace cooking processes; in studies of the ejection of matter from stars (because it seems that at least some stars are made not of virgin wool, but shoddy; that is, material left over from other stars and gathered up again); in studies of the chemical composition of nebulae; and in studies of the physical form of bodies such as our Moon, whose surface may record in a language which we cannot yet read, the history of these early times.

HABITABILITY OF OTHER WORLDS

The second question is that of the habitability of other bodies in space.

The knowledge which is needed to carry out these two objectives—to understand the origin of the world and to find out about life in outer space—can be sought both by ground-based telescopes and laboratories and by the methods of space exploration. Space satellites and probes have, however, two important advantages which indicate the role that they should play in this problem. In the first place, satellites and space probes are able to get above the atmosphere and thus to examine the whole range of the electromagnetic vibrations which run from gamma rays and X-rays up to the long radio waves. In figure 22 is represented the electromagnetic spectrum, which is a compact summary of one of the facts of life with which astronomers must deal. Our knowledge in space has, up to the last few years, been limited to the information which we could collect through the narrow gap which you see in the visible and infrared range, which represents ordinary light, and the other gap in the short-wave radio region. The whole area of the gamma rays, the X-rays, and the far ultraviolet rays has been closed to us by the absorption of light by oxygen and nitrogen, and that of the near ultraviolet by absorption by ozone in the Earth's upper atmosphere. In this region there lie, in all probability, the clues to the behavior of the aurora and the ionosphere. It is reasonable to think that from the X-ray portion of this region we shall some day find clues to the origin of cosmic rays or at least to their distribution throughout the galaxy.

Since so much of the universe is filled with the faintly glowing gases which we call the bright nebulae, it is interesting to notice that there is some evidence, from studies conducted in the ultraviolet, that there is a solar nebula attached to the Sun and extending out to the Earth and enveloping it. We thus have the possibility of studying the mechanics of a nebula at firsthand; and in fact such studies are now being carried on in the ultraviolet region from rockets and satellites.

In the near ultraviolet region lie the lines which we need to measure the abundance of some of the most important elements which will help to decide between theories of the origin of the universe. Sulfur, for example, is a necessary constituent of life and is abundant in

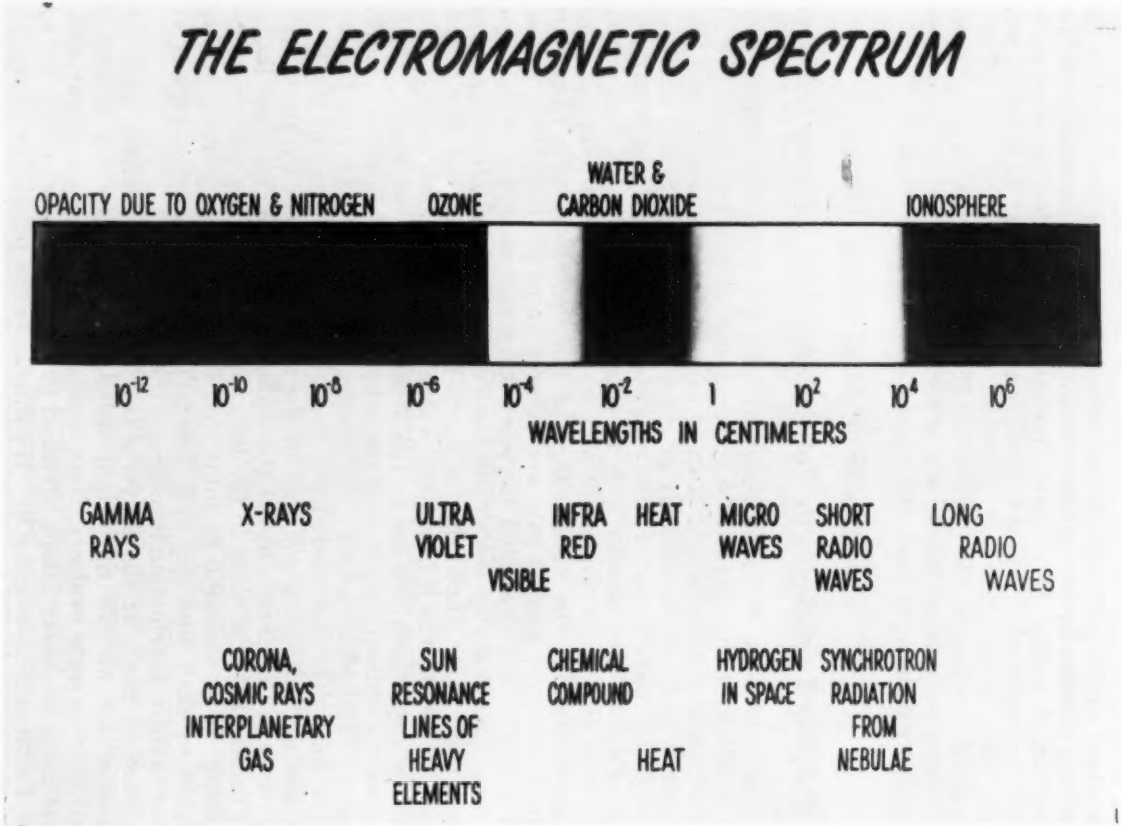

THE ELECTROMAGNETIC SPECTRUM
OPACITY DUE TO OXYGEN & NITROGEN
OZONE
WATER & CARBON DIOXIDE
IONOSPHERE
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
1
10^{2}
10^{4}
10^{6}
WAVELENGTHS IN CENTIMETERS
GAMMA RAYS
X-RAYS
ULTRA VIOLET
INFRA RED
HEAT
MICRO WAVES
SHORT RADIO WAVES
LONG RADIO WAVES
VISIBLE
CORONA, COSMIC RAYS INTERPLANETARY GAS
SUN RESONANCE LINES OF HEAVY ELEMENTS
CHEMICAL COMPOUND
HEAT
HYDROGEN IN SPACE
SYNCHROTRON RADIATION FROM NEBULAE

FIGURE 22

meteorites but not in the Earth's crust. It has very strong lines in the ultraviolet and only very weak ones in the visible region. A study of the cosmic abundance of sulfur has to be conducted in the ultraviolet. The situation is much the same with respect to other acid-forming elements.

On the other side of the visible spectrum is the infrared. Here our vision from the ground is blocked by absorption from water vapor and carbon dioxide. The study of this region is likely to contribute particularly to the second objective of determining the habitability of the planets. In the small portion of this region partially available to us have been found the weak bands that seem to show that there is life on Mars. If we can explore the rest of the infrared region, we expect to find clues having to do with the presence of chemical compounds (as distinguished from elements which is what we see at the other end of the spectrum). We can hope to find out, for example, something about the type of rock which exists on the moon and perhaps on other planets and about gaseous compounds in the atmosphere of the plants. We can, perhaps, look for gaseous compounds in interstellar space.

Passing over the radio gap, we come to the absorption produced by the ionosphere which covers the long wavelength of the spectrum. We can only imagine what might lie hidden here. It is reasonable to expect that we would get evidence on the very large scale turbulent movements of the gases within our galaxy. It is conceivable also that in this area we may find radiations coming from outer galaxies and perhaps permitting extension of our grasp of the universe beyond that now available.

We see that the extremely long wavelengths and the extremely short wavelengths may well give us clues to the construction of the universe and ultimately to its origin while gaps in the infrared and heat radiation may tell us something about conditions on other planets.

PARTICLES IN SPACE

The other avenue of exploration which is particularly suitable for a space agency is the avenue of direct contact with objects which we otherwise know only indirectly.

What I mean is that by means of our space vehicles we can plan to capture, for example, cosmic rays, before they have been transformed by passage through the atmosphere, or interplanetary gases and dust, or micrometeorites, meteorites, meteors, or perhaps even samples of asteroids, satellites, or planetary surfaces. Examples of these are pictured in figure 23.

These direct examinations of astronomical bodies are likely to have an enormous influence on our thinking about astronomy. At the present time, very large pieces have been put together of the jigsaw puzzle which is presented to us by the astronomical world. It is typical, however, that the place in which these large pieces of the puzzle fit into the overall frame is not known. Perhaps the best example is the study of meteors.

It is often a surprise to those outside the field of astronomy to know that astronomers are not at all certain that the meteors which we observe every summer night are not necessarily the same sort of objects

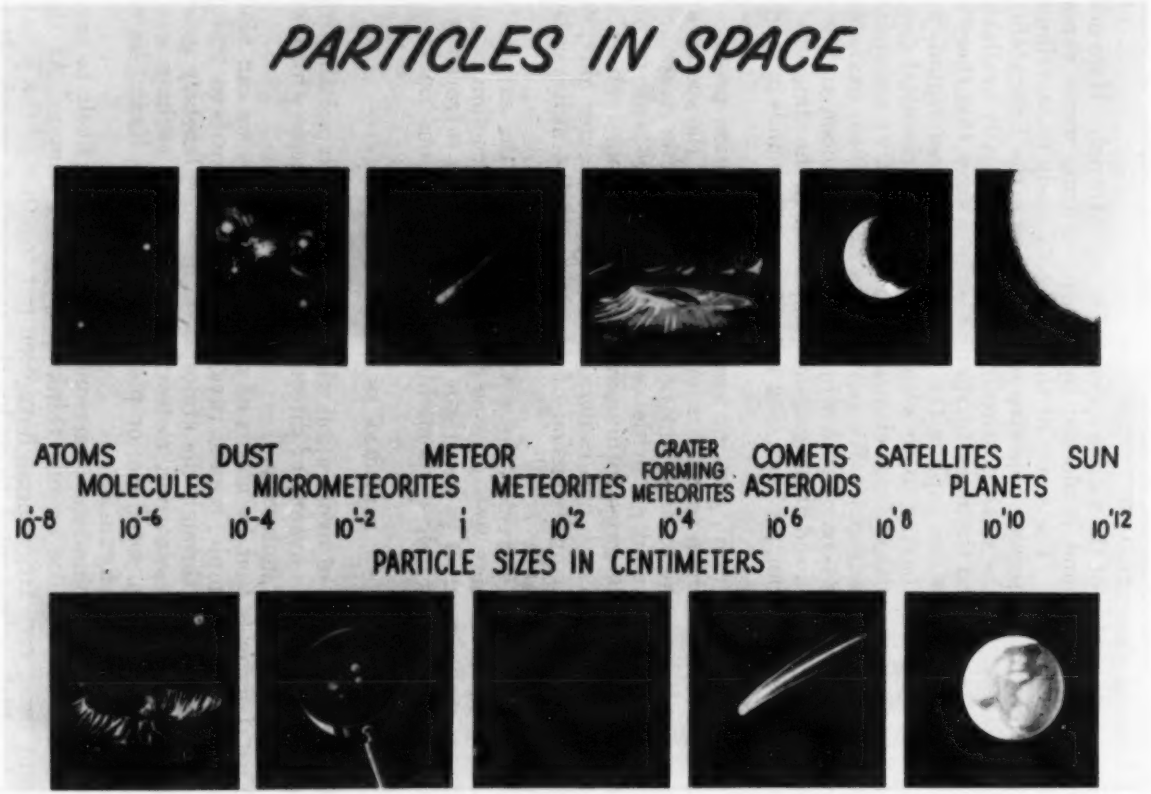

PARTICLES IN SPACE
ATOMS
MOLECULES
DUST
MICROMETEORITES
METEOR
METEORITES
CRATER FORMING METEORITES
COMETS
ASTEROIDS
SATELLITES
PLANETS
SUN
10^-8
10^-6
10^-4
10^-2
1
10^2
10^4
10^6
10^8
10^10
10^12
PARTICLE SIZES IN CENTIMETERS

FIGURE 23

as the meteorites which we occasionally find on the ground. It is apparently not only a matter of size; they do not seem to come at the same times of the year. Moreover, the physical strength of the meteors as far as it can be deduced from a knowledge of the heights at which meteors break up, does not fit what we know about the meteorites. We know that the meteors are related to the comets; we have seen comets break up and leave trails of meteors behind. If we could capture and examine a single meteor in space it would illuminate the physical nature of these mysterious bodies enormously.

Smaller than the meteoriates are objects which are believed to exist in space and are called the micrometeorites. Theory says that a large number of these objects should bombard the earth's atmosphere every second. Satellite experiments have given fairly reliable information during the past year concerning their density in space. At the same time students at the surface of the earth have searched in material collected in the upper atmosphere for particles which might have been micrometeorites. They have found among others small bodies which under the electronic microscope seem to consist of an infinitesimal woolly material. Are these objects really micrometeorites or not? A study of genuine micrometeorites collected in space would at once clear up this problem and would lend point to the research that is being conducted in ground laboratories.

From studies of apparent distribution of stars in space we know that there must exist vast clouds of dust. There is every reason to think that the solar system lies in the area which is filled, though very thinly, by these clouds. Samples of the dust, if they could be collected, would at once illuminate the whole subject of cosmic dust clouds.

Turning to the other side of the particle spectrum, that is to the particles of large size, the most interesting possibility it seems to me, is the possibility that some of the stones which we see on the surface of the Earth may have come from the Moon. When we consider the extreme violence with which the lunar craters appear to have been formed, it is clear that particles thrown from them, whether by volcanic explosion or by meteorite impact, must have emerged with velocity nearly sufficient, or perhaps quite sufficient, to escape the Moon's gravitational attraction. Some of them probably fell to the surface of the Earth. A single sample of the lunar surface might guide us to a knowledge of which stones on earth have fallen this way and thus make applicable to astronomy a considerable volume of ground-based petrographic research. At the same time, it would permit us great insight into the process by which the Moon was formed, and would give another sample of the matter of the universe.

Close range examination of the lunar surface would also help to tell us how it was formed. This will help us in a very direct way to understand the origin of the solar system, because the Moon's surface was apparently formed then. It has been suggested that some of the so-called seas resulted from the infall of large pieces of the early Earth and Moon system. If we could sample the surfaces of these seas, we could find out whether they are really lava flows, or are dust pockets as suggested by Gold.

In the same way, it can be hoped that ultimately the surfaces of Mars and Venus can be investigated by direct sampling. We know much less now about the planets, however, and hence we cannot expect the breakthroughs that come when we put in place an assembled mass of knowledge.

LONG-RANGE PROGRAM

The first phase of the long-range program will be the development of an orbiting stabilized platform. On this platform, telescopes and radio antennas will examine the universe in the wavelengths denied to us at the ground. The observations will continue the work already begun in rockets on the light of the solar nebula and its chemical composition, and on the large ultraviolet nebulosities. Studies will be extended to the infrared (especially for the nearer planets) and to the long radio waves.

A series of soft landings will be made on the Moon with instruments designed to study the radioactivity, the underground noises, the chemical composition, and the surface structure. These will be aimed in part at comparing the lunar surface with terrestrial rocks.

Eventually, it is planned to establish an observatory on the Moon's surface. This will have the advantage that it will not be in rapid motion; this will considerably simplify and improve the quality of observations in several ways.

All of these programs will require not only the development of a stable platform, X-ray, ultraviolet, and infrared telescopes, and long wavelength antennas, but also extensive improvements in telemetering techniques, so that transmission of the resulting information to the ground in sufficient volume will be possible.

IMMEDIATE PROGRAM

The immediate program will continue and extend to the southern sky the survey of the newly discovered nebulosities in the far ultraviolet by means of rockets. These measurements are being undertaken to determine the nature and sources of these emissions. Concurrently, stellar photometry measurements will be made in the near and far ultraviolet spectrum region to extend magnitude systems to ultraviolet. Emphasis is being given to extending our observations into the previously unexplored far infrared and high energy gamma-ray spectral regions by means of scanning satellites and rockets. Apart from their intrinsic value, these surveys are essential as groundwork for the satellite observatory program.

Studies of the solar ultraviolet and X-ray spectra will be extended to include long-term variations, line profiles, distribution across the disk, and the spectra of the coronal X-ray flux. These studies will be carried out in a series of rocket firings and with satellite borne pointing devices.

Deep space probes such as Pioneer V are being used to determine the nature and extent of the solar nebula and interplanetary medium.

LUNAR EXPLORATION

By E. M. Cortright, Assistant Director, Lunar and Planetary Programs, and J. Allen Crocker, Chief, Program Coordination, Lunar and Planetary Programs, NASA

OBJECTIVES

The NASA has established a sound program for the exploration of the Moon, Mars, and Venus which is designed to provide leadership in acquiring scientific knowledge about these bodies. The program is not an extravagant one. Rather, it is soberly conceived to exploit an orderly evolution of launching vehicles, spacecraft, and scientific payloads to the achievement of several selected goals. Within the next half decade these goals may be simply illustrated by their related missions, which are listed below with their dates of earliest achievement:

1960: Interplanetary probes.
1960: Lunar orbiters.
1961–62: Lunar impacts (reconnaissance).
1962: Planetary probes to Mars and Venus.
1963–64: Lunar soft landings.
1965: Planetary orbiters to Mars and Venus.
1965: Lunar soft landing with mobile vehicle.

This mission schedule has been developed in accord with the following principles:

1. Select the most important goals and pursue them with determination.
2. Establish an evolutionary sequence of missions where each step paves the way for the more difficult phase to follow and which makes full use of increased technological capability as it becomes available.

The scientific objectives of these missions are no less exciting than the spectacular flights themselves. As our nearest major body in the solar system, unchanged by winds and rain in the several billion years of its (and the Earth's) existence, the Moon offers unique opportunities for a better understanding of the solar system. The discovery of some form of life on Mars and Venus could prove far more than a scientific curiosity. Just as the planned missions constitute an orderly sequence of technological and scientific development, so do they lay the groundwork for the more difficult missions to follow. The lunar and planetary exploration program is now in its formative stages.

LUNAR MISSIONS

These missions are clearly oriented toward the achievement of controlled lunar landings. It is the feeling of the NASA that this approach will yield the maximum scientific results and will pave the way for more ambitious lunar missions at some later date. The series begins with two attempts to place an instrumented payload in orbit about the Moon using the Atlas-Able booster. These mis-

sions represent the best current capability and are, in fact, the third and fourth attempts at this mission following two failures in 1959.

These missions utilize a spin-stabilized payload with rudimentary but effective midcourse guidance, without which the mission could not be accomplished at this time. The payload contains a variety of radiation detection experiments to make measurements in the lunar environment. As an "anchored" space station away from the Earth's influence, the payload assumes additional importance when its long-term measurements are compared with related measurements in the vicinity of the Earth.

In 1961 the NASA will begin the second phase of the lunar program. The Atlas-Agena B will be used to launch a new spacecraft to achieve a controlled lunar impact with survivable equipment.

A "spacecraft" is a vehicle designed to fly through space carrying a useful payload and maneuvering as required to maintain the desired course and orientation. In earlier days the scientific payload and telemetry equipment were packaged into a structure which was little more than a can and which either tumbled freely or was spin stabilized. In contrast, the soft landing lunar spacecraft of the future may be likened to a fighter aircraft in complexity and cost. This is readily understandable when one considers that this remote descent to the lunar surface is without benefit of an atmosphere and that the total deceleration and landing is dependent on rocket braking and appropriate electronic sensing equipment to guide and control this braking.

Returning to the sequence of Atlas-Agena B launchings, the first two will actually not be directed toward the Moon but rather into orbit about the Sun to test vital spacecraft components and at the same time conduct selected scientific experiments. Toward the end of 1961 the first of three attempts at the complete lunar mission will be ready. The spacecraft for this mission will consist of two sections. The main section will contain guidance and control, telemetry, and propulsion equipment which will make it possible to impact the Moon within a predetermined area and with attitude control during the entire flight. In addition to carrying scientific instruments for measurements in cislunar space, this section of the payload will carry a television camera capable of transmitting during the final moments of flight pictures of the impact area having optical resolutions of less than 10 feet. The spacecraft is also being designed to carry a capsule which will be slowed by a retrorocket from about 8,000 feet per second so that its impact velocity will be less than 500 feet per second. Survivable equipment within the capsule may include instrumentation to study the lunar surface consistency, structure, and temperature.

In 1963 the availability of the powerful Centaur should make possible the first true lunar soft landing of a spacecraft carrying television, a seismograph, a spectrometer, and radiation detection devices among other relatively fragile scientific instruments to observe and analyze the lunar surface and subsurface properties. Telemetry and an electric power supply must also be included in the same 600 pounds of structure and equipment which can be deposited relatively gently on the lunar landscape. The television reconnaissance of the terrain obtained in the preceding Agena series should facilitate the

selection of design criteria for the Centaur spacecraft landing structure. A long service span is predicted for this spacecraft since spot investigations of many lunar areas will be conducted over a period of years.

The Saturn soft landing spacecraft will be required for those areas of the Moon which are to be explored intensively, either for purely scientific reasons or to lay the groundwork for manned landings. This spacecraft with its payload will weigh at least several times that of the Centaur. The first payload, planned for 1965 with a 3- to 4-year leadtime for development, is planned to be self-powered for mobility over the lunar surface. By this technique the actual area which may be explored and sampled will increase manifold. Here again, television will play a key role in this remote exploration.

PLANETARY AND INTERPLANETARY MISSIONS

A Thor-Able launched successfully March 11, 1960, as Pioneer V and a Thor-Delta probe still to be launched will obtain scientific measurements of magnetic fields and of particle and electromagnetic radiation fields deep into interplanetary space. The first capability of launching probes into the vicinity of Mars and Venus will come in 1962 when it is planned to use the Centaur launch vehicle and a variation of the spacecraft designed for use on the Atlas-Agena lunar missions. These planetary probes are designed to pass close enough to the planets to permit critical scientific measurements to be made and transmitted back to Earth. Television and/or spectrographic observations are being considered, although difficult to achieve due to guidance problems and uncertainties in the position of the planets.

In 1964 another favorable opportunity to fire at Venus will occur. This flight will probably be used to test stellar navigation equipment planned for operational use aboard the Mars and Venus orbiting spacecraft scheduled for launch with the Saturn in 1965. These latter spacecraft will weigh several thousand pounds and are conceived as ejecting instrumented capsules to penetrate the atmosphere of the two planets.

ADVANCED INSTRUMENTS

The exploration of the Moon and planets involves complex payloads containing instruments for the measurement of a wide variety of phenomena. The program was initiated in the fiscal year 1959 by the procurement of relatively simple, first-generation instruments; either off-the-shelf items or those requiring a minimum of research for development. At the same time, necessary research studies were started for the development of more complex, second-generation instruments for later flights.

The complexity of physical phenomena in space necessitates the use of numerous scientific instruments, each requiring for its successful development the highest technical talent available. Two principal categories of flight instruments are needed to achieve the objectives of the lunar and planetary exploration program: (1) specialized instruments for specific measurements, such as analyses of the surface of the Moon or planets, which frequently require long leadtimes for intensive research on many problems facing the experimenter; and

(2) instruments to measure interplanetary phenomena while the payload is on its way to a target such as the Moon or other planets. These instruments measure cosmic rays, magnetic fields, meteorites, solar rediation, and similar space phenomena. While initial space probes were able to measure the basic values of these quantities, consecutive developments, increased sensitivity, and progress in measuring techniques are required to measure the same quantities at vast distances away from the Earth deep in interplanetary space.

For example, the development of lunar seismograph systems for measurements of the interior of the Moon has been started; a simplified system will be in the first payload impact on the Moon. Concurrently, the development of an advanced seismograph system is underway for later flights to the Moon which will deposit a seismograph for sustained operation on the lunar surface. Another example is the development of television systems for obtaining pictures of the lunar surface as well as of Mars and Venus. Initial instrumentation consisted of simple scanning devices which relayed crude pictures from outer space. To obtain high-resolution pictures of the lunar surface, a necessary preview to selection of landing sites, an advanced television system is under development. For planetary exploration, different requirements will be placed on the capabilities of television systems to transmit information over millions of miles. And finally, the analysis of lunar surface samples will be greatly aided by systems which obtain and transmit microscopic pictures back to Earth. These vastly different television systems require and are receiving study and development.

As the payload weight capabilities of space probes increase, current progress in the development of scientific instrumentation will lay the basis for the future employment of greatly advanced instrumentation to enhance our knowledge of the solar system.

MISSION ACCOMPLISHMENTS

In the spring of 1959 Pioneer IV operations were being completed. This was the last of a series of five (three Air Force and two Army) Moon probes. Pioneer IV was tracked to a distance of 407,000 miles from Earth before its batteries went dead. This has stood throughout the past year as a distance record in space communications.

Pioneer V was successfully launched on March 11, 1960 from a Thor-Able booster. This is the first mission to place an artificial planet in orbit between the Sun and the Earth. Previous missions (Pioneer IV, March 3, 1959, and the Russian Lunik I, January 2, 1959) placed manmade planets in orbit at a greater distance than Earth from the Sun.

Pioneer V has already exceeded the record of Pioneer IV for communications. Since it carries provision to convert the Sun's energy to recharge its batteries and is believed to carry the most powerful transmitter ever flown (30 times more powerful than any U.S. experimental space transmitter to date), it should be possible to maintain communications at distances up to 50 million miles. At that distance it would take radio waves approximately 4½ minutes to make the trip.

Additional experiments in the Pioneer V payload include:

High-energy radiation counter to measure "hard" radiation, particularly that hurled into space by the Sun. A similar instrument in Explorer VI tentatively located a band of hitherto undetected high-energy radiation near the inner edge of the Earth's great radiation belt.

Total radiation flux: An ionization chamber and Geiger-Mueller tube particularly sensitive to medium-energy radiation.

Micrometeorite counter to measure the number and momentum of meteoric dust particles striking the probe.

Magnetometer to determine the strength and direction of magnetic fields in space.

Aspect indicator to tell when it "looks" directly toward the Sun and thus produce more meaningful information from the other experiments.

Pioneer V is the third in a series of "paddlewheel" payload flights. They include Explorer VI, launched August 7, 1959, into a highly elliptical Earth orbit, and an Atlas-Able space probe which failed 45 seconds after launch on November 26, 1959, when its nose fairing broke away prematurely.

SPACECRAFT FOR AGENA SERIES

The Jet Propulsion Laboratory will design and develop the basic spacecraft carrying a survivable package slowed down by a retrorocket for Moon missions (fig. 24); and carrying an instrumentation tower for planetary probes (fig. 25). The lunar impact missions have been previously described as directed toward reconnaissance prior to impact and suvival of some scientific equipment. The planetary missions will conduct experiments in interplanetary space and will study the planets at their point of closest contact. The program covers development of flight hardware from the early research phase, through the "breadboard" and prototype equipment, to flight articles.

To be able to accomplish the Agena missions it has been necessary to develop three-axis stabilization of the spacecraft and a guidance system which is controlled by radio from the Earth. Stabilization is accomplished by the actuation of low pressure cold gas (nitrogen) jets. Sensing for the attitude control system relies upon the establishment of a spacecraft-Sun line and a spacecraft-Earth line. Midcourse guidance relies upon attitude positioning with respect to these reference lines, to aline the engine nozzle in the direction of the desired thrust. The midcourse guidance engine is designed to use a monopropellant (hydrazine).

DESIGN STUDY AND PRELIMINARY ENGINEERING FOR CENTAUR AND SATURN SPACECRAFT

The relatively short lead time before the Centaur lunar soft landing mission requires that specifications be prepared and preliminary engineering accomplished as rapidly as possible so that the critical subsystems (navigation, guidance and control) can be ready at the earliest possible date.

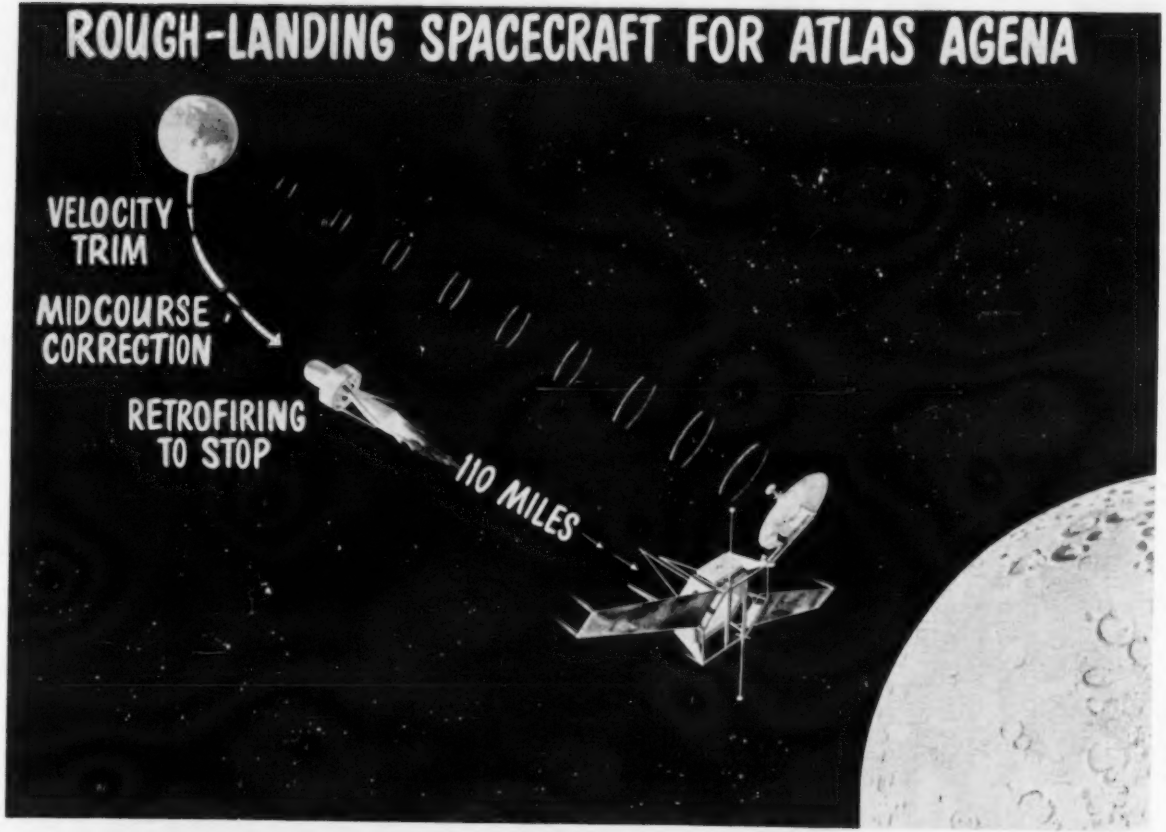

ROUGH-LANDING SPACECRAFT FOR ATLAS AGENA
VELOCITY TRIM
MIDCOURSE CORRECTION
RETROFIRING TO STOP
110 MILES

FIGURE 24

FIGURE 25

A spacecraft to be used with the Centaur booster is being developed primarily for soft landings on the Moon. Another will be suitable for missions to the planets Venus and Mars. Such a spacecraft will be considerably more sophisticated than anything previously employed and will require subsystems of midcourse guidance, terminal guidance, and attitude control whose functions are sufficiently peculiar to this vehicle to require separate development.

The midcourse guidance to be developed for the Centaur-boosted spacecraft is a precision vehicle-borne system which has as its function the correction of flight path after separation from the booster, and navigation between the point where booster fuel burns out and the position in space where the terminal guidance takes over. The components would be star trackers; planet seekers; Sun seekers; equipment to issue commands for steering, thrust initiation and cut off; computers; precision timekeepers; radio overrides; and necessary power supplies.

The attitude control system to go with the spacecraft boosted by the Centaur has as its function stabilization of pitch, roll, and yaw of the vehicle, determination of the vertical, component orientation and stabilization, thrust orientation and antenna pointing. Equipment would be torquers, autopilot, radiation sensors, gyro platform, and programer.

The terminal guidance in the lunar landing spacecraft is designed to position the vehicle on the surface of the Moon to within ± 50 miles, to circularize the orbit, to sense forward velocity and horizontal drift with respect to the surface so as to effectively slow the spacecraft from about 8,000 feet-per-second to a soft vertical landing, and to accommodate hitting the proper corridor for a successful return through the atmosphere to the Earth. Equipment needed includes thrust controllers to slow the spacecraft, three-axis doppler to detect drift with respect to a point on the surface as well as altitude above the surface, TV monitors, radio override, vehicle-contained computers, inertial platforms, radio program changer, and associated power supplies.

The situation with the Saturn spacecraft allows more study time. The extreme complexity of the mobile payload for the Saturn lunar soft landing spacecraft as well as the complexity of the planetary orbiter with landing "probes" dictate very careful planning for these projects.

MIDCOURSE AND TERMINAL GUIDANCE

By Benjamin Milwitzky, Head, Geodetic and Navigational Satellites Program, NASA

For many deep space missions, such as those where we might want an accurate approach to a planet, injection guidance is not sufficiently accurate to do the job. The situation might be likened to trying to aim a rifle at a target many miles away. The amount of accuracy that you would require in your aiming just cannot be achieved. For missions of this type we therefore have to devise equipment that will operate subsequent to the injection phase and which will guide the vehicle all the way to the target. This concept is illustrated in figure 26.

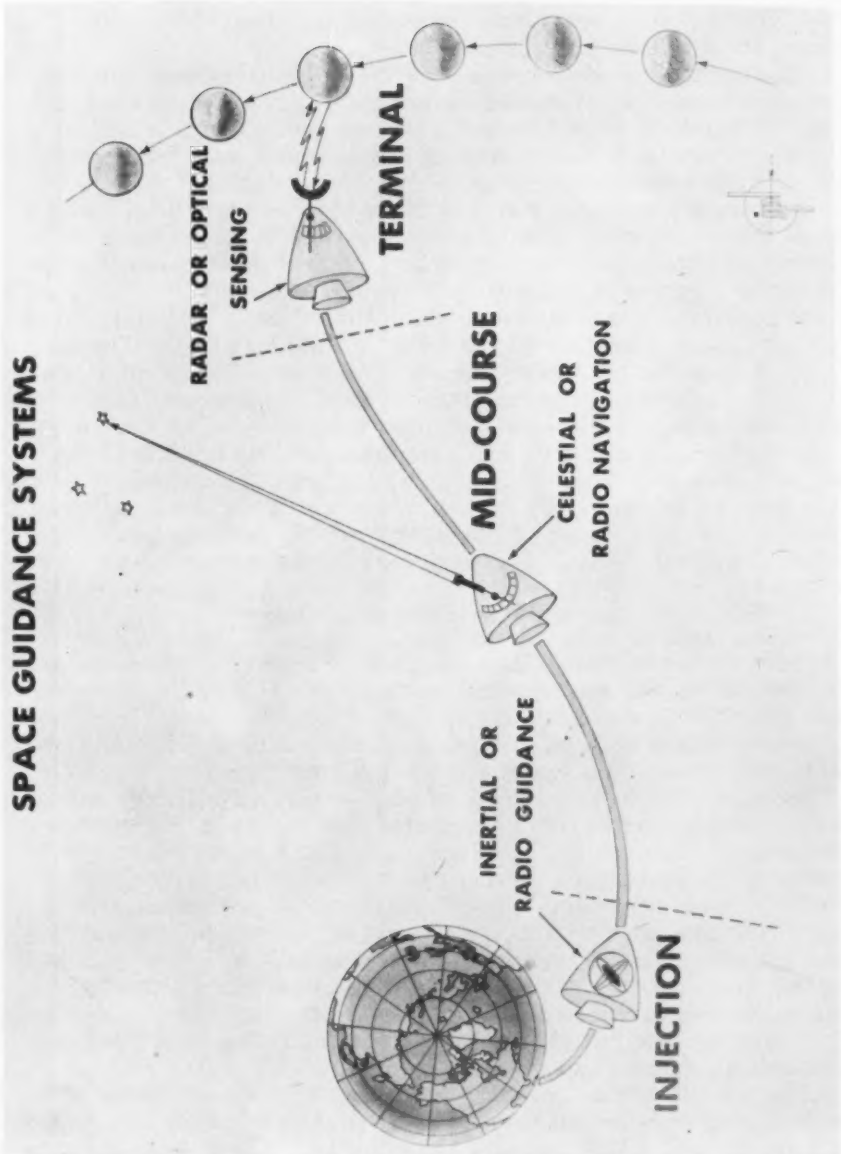

SPACE GUIDANCE SYSTEMS
RADAR OR OPTICAL SENSING
TERMINAL
MID-COURSE
CELESTIAL OR RADIO NAVIGATION
INERTIAL OR RADIO GUIDANCE
INJECTION

FIGURE 26

The problem basically resolves itself into two natural phases, a midcourse navigational phase and a terminal guidance phase. In the midcourse phase we could use celestial navigation techniques very much like those the mariner uses, observing the stars, the planets, and the Sun. Or, we could use radio techniques to track and control the vehicle from the Earth.

In the terminal guidance phase, we would probably base our guidance on radar or optical sensing techniques which would actually look at our destination. The terminal guidance phase requires especially accurate guidance because many of our missions will have specific scientific purposes necessitating closely controlled maneuvers.

For example, we might want to place a very accurate orbit about a planet for a particular scientific investigation or we might want to effect a soft landing on the moon or on a planet. This terminal phase is the most rigorous in terms of the accuracy required.

The midcourse phase is one in which the vehicle is coasting. It is coasting along a planetary ellipse following Kepler's laws. The vehicle itself does not have any inherent means of changing its course. It does not have any means of steering itself. If we want to change its course, we have to provide it with an impulse.

During the near future we will have to carry along additional chemical fuel to operate the rocket engine to supply this impulse. At a later date we may have ion engines, nuclear rockets, or we may even be able to use the pressure of the energy coming from the Sun—solar radiation pressure—to effect these changes in the course of the vehicle.

MIDCOURSE NAVIGATION SCHEMES

Figure 27 shows some of the ideas which might be considered for performing the midcourse navigation function. This figure shows concepts of a celestial and a radio technique. With the celestial technique the device is completely self-contained in the vehicle. With the radio technique the vehicle is essentially guided from the ground.

The celestial technique would employ optical or infrared sensors which would be used as Sun seekers, star seekers, or planetary seekers. For example, this one might be observing the Earth, or it might be observing the destination planet. These optical or infrared seekers would be small telescopes which focus light on a photoelectric cell which generates an electrical impulse. Very clever devices and systems have been developed whereby these seekers will first start out hunting and then will lock onto their target, planet or star as the case may be; and when this happens you have a situation where one seeker is pointing this way, another seeker is pointing that way, a third may be pointing another way.

As the vehicle moves through space its position relative to the celestial bodies changes so that these angles change, and inside the vehicle we have devices which measure these angles. These measurements are transmitted to a computer in the vehicle. This computer performs the navigational calculation to determine where the vehicle is. It has stored in it the formulas for calculating the best trajectory from the point where the vehicle is to where we want it to go. It further computes the amount of impulse required to make the vehicle perform this maneuver. It turns these numbers into actual physical commands

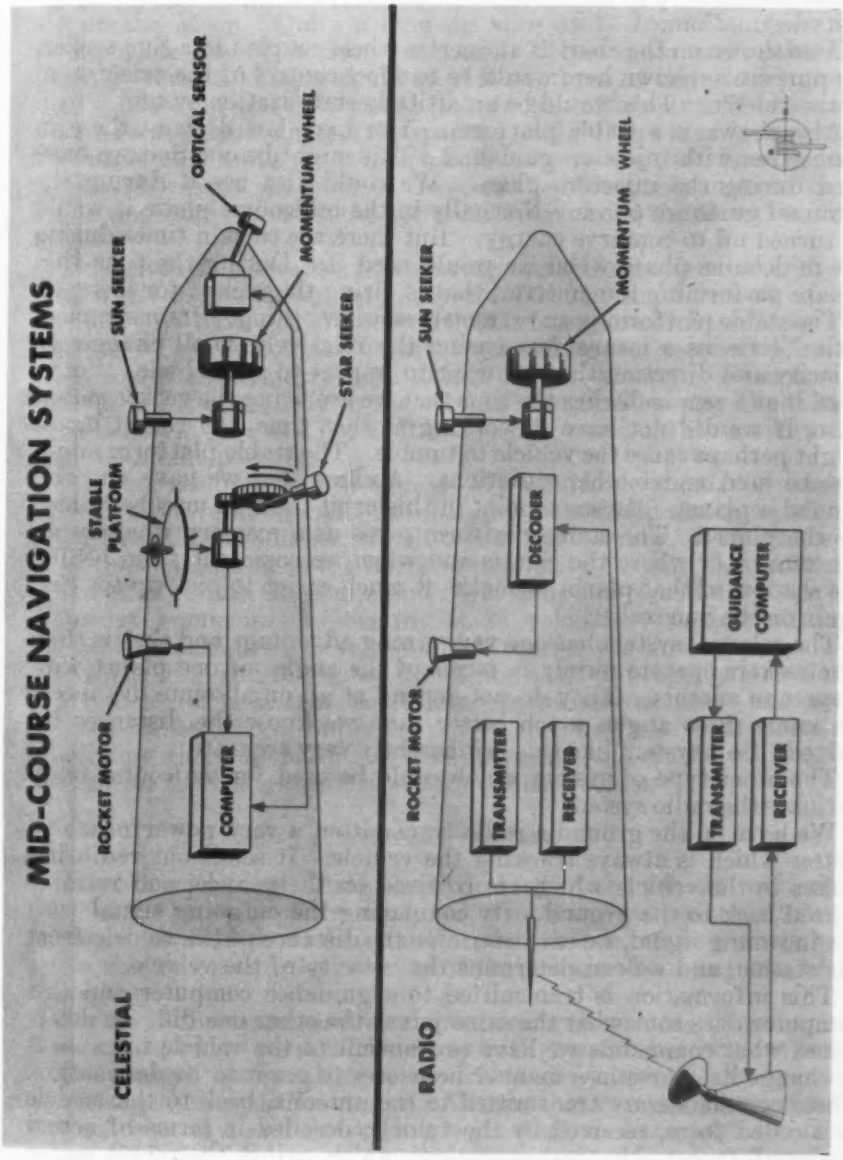

MID-COURSE NAVIGATION SYSTEMS
CELESTIAL
ROCKET MOTOR
STABLE PLATFORM
SUN SEEKER
OPTICAL SENSOR
MOMENTUM WHEEL
STAR SEEKER
COMPUTER
RADIO
ROCKET MOTOR
SUN SEEKER
MOMENTUM WHEEL
DECODER
TRANSMITTER
RECEIVER
GUIDANCE COMPUTER
TRANSMITTER
RECEIVER

FIGURE 27

which operate this rocket. First, it tilts the rocket motor, that is, swivels it in the proper direction. It then meters out the amount of fuel required to provide the necessary impulse. It finally fires the rocket motor to put the vehicle on the proper trajectory to take it to its destination.

Also shown on the chart is an inertia wheel coupled to a Sun seeker. Its purpose as shown here would be to effect control of the orientation of the vehicle. This would be an attitude stabilization system.

Also shown is a stable platform. You have heard about these in connection with injection guidance. This might be one that we have used during the injection phase. We could also use it during the terminal guidance phase. Normally in the midcourse phase it would be turned off to conserve energy. But there are certain times during the midcourse phase when we would need it. During the time that we are performing a maneuver, that is, firing the rocket, for instance.

The stable platform is an extremely sensitive thing. Its instrumentation gives us a means for sensing the relatively small changes in velocity and direction that we want to impart to the vehicle. So we need it as a sensor during the time that we are firing the rocket motor. Also, if we did not have it working at that time, the rocket motor might perhaps cause the vehicle to tumble. The stable platform might also be used under other situations. Assume that we have an orbit around a planet. At some point in this orbit the Sun may be hidden by the planet. The stable platform gives us a memory whereby we can remember where the Sun is and when we come out from behind the shadow of that planet, it makes it much easier to pick up the Sun again on the Sun seeker.

The celestial system has one very strong advantage and that is this: The seekers operate purely in terms of the angles of one planet with respect to another. They do not depend at all on absolute distances; we know these angles much better than we know the distances involved. So a system like this is inherently very accurate.

The other type of system which could be used for midcourse navigation is the radio system.

We have on the ground a radio transmitter, a very powerful transmitter which is always tracking the vehicle. It sends out radio impulses to the vehicle which are received on the vehicle, and retransmitted back to the ground. By comparing the outgoing signal with the incoming signal, we can determine the distance of the vehicle from the station, and we can determine the velocity of the vehicle.

This information is transmitted to a guidance computer and this computer does somewhat the same job as the other one did. It determines what commands we have to transmit to the vehicle to cause it to change its course in a manner necessary to get it to its destination. These commands are transmitted to the antenna, back to the vehicle in a coded form, received by the vehicle, decoded in terms of actual push-pull type mechanical operations which swings the rocket motor and fires the necessary charge for course correction.

These are not real systems. They are essentially the elements of the problem, the types of equipments which would go into the systems, and the philosophies which could be used to do the job.

TERMINAL GUIDANCE SCHEME

Finally we have the problem of terminal guidance. This system, figure 28, might be considered as one that would be suitable for landing on the Moon. Quite a long distance away from the Moon we would make use of horizon scanners. These again are optical or infrared devices. There would be perhaps three of them looking out, they would hunt and they would find the line of demarcation between the surface of the Moon and the space beyond. There is a big temperature difference, and they work on this temperature difference to lock onto the horizon. As we come closer to the Moon, this angle becomes larger and larger because the apparent diameter of the Moon becomes larger.

This gives us a means of measuring our distance from the Moon. It also gives us another very important thing, the direction of the vertical. We have to know our vertical reference in order to make our landing. Therefore, since we are approaching the moon at 7,000 to 9,000 feet per second, we have to kill off the velocity. We not only have to kill it off exactly in the vertical direction but any slight misalinement will give us a horizontal velocity; we would move sideways, hit a mountain, perhaps.

Here we need extreme accuracy. We would use a radar altimeter, such as we have in aircraft, for altitude. We would also use perhaps Doppler radio techniques, which would tell us very closely the vertical velocity as well as the horizontal velocity. Again this information would go into the computer. The computer would calculate the necessary commands to destroy these velocities; these commands would be transmitted to valves which control the flow of propellant into the engine and to gimbal the engine so as to properly slow down the vehicle. The system would also use inertial elements and autopilots because we are applying power and we need some means of stabilizing the vehicle during this operation. If we do it properly we can set the thing down in a very gentle manner.

ATTITUDE CONTROL

In addition to controlling the trajectory of the vehicle we have to control the attitude of the machine. For many purposes we have to stabilize the attitude, and to stabilize the attitude means that we have to be able to control the rotation of the vehicle about any one of its three axes.

Figure 29 illustrates several ways of doing this.

In space, where we don't have any real power, where we are coasting, we might use small gas jets. These gas jets would be operated either together or differentially. Assume that one gas jet were made to push one way, and the other gas jet were made to push the other way. This would give us a rolling movement. If selected gas jets were pushing in the same direction it would give us a yawing moment; by this technique we could make the vehicle rotate about any of its three axes.

Or we could use momentum wheels. These make use of the principle that with every action there is an equal and opposite reaction. In

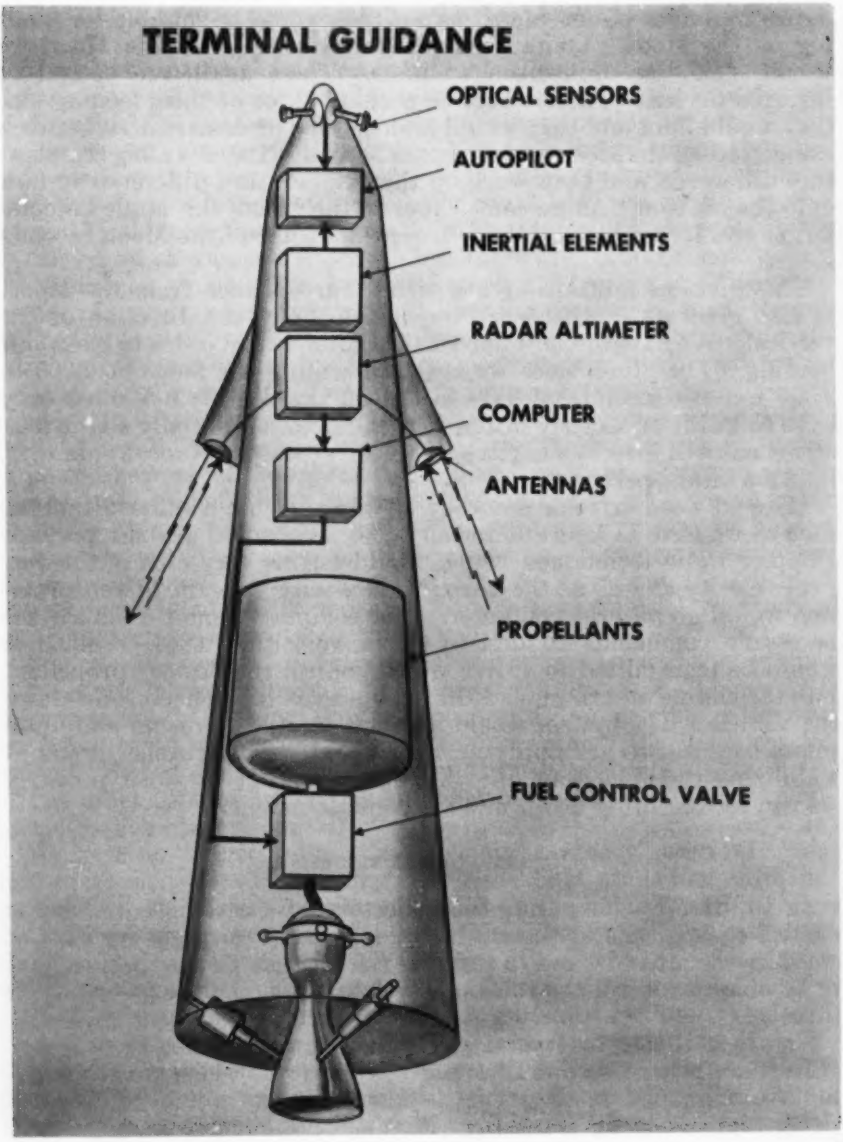

TERMINAL GUIDANCE
OPTICAL SENSORS
AUTOPILOT
INERTIAL ELEMENTS
RADAR ALTIMETER
COMPUTER
ANTENNAS
PROPELLANTS
FUEL CONTROL VALVE

FIGURE 28

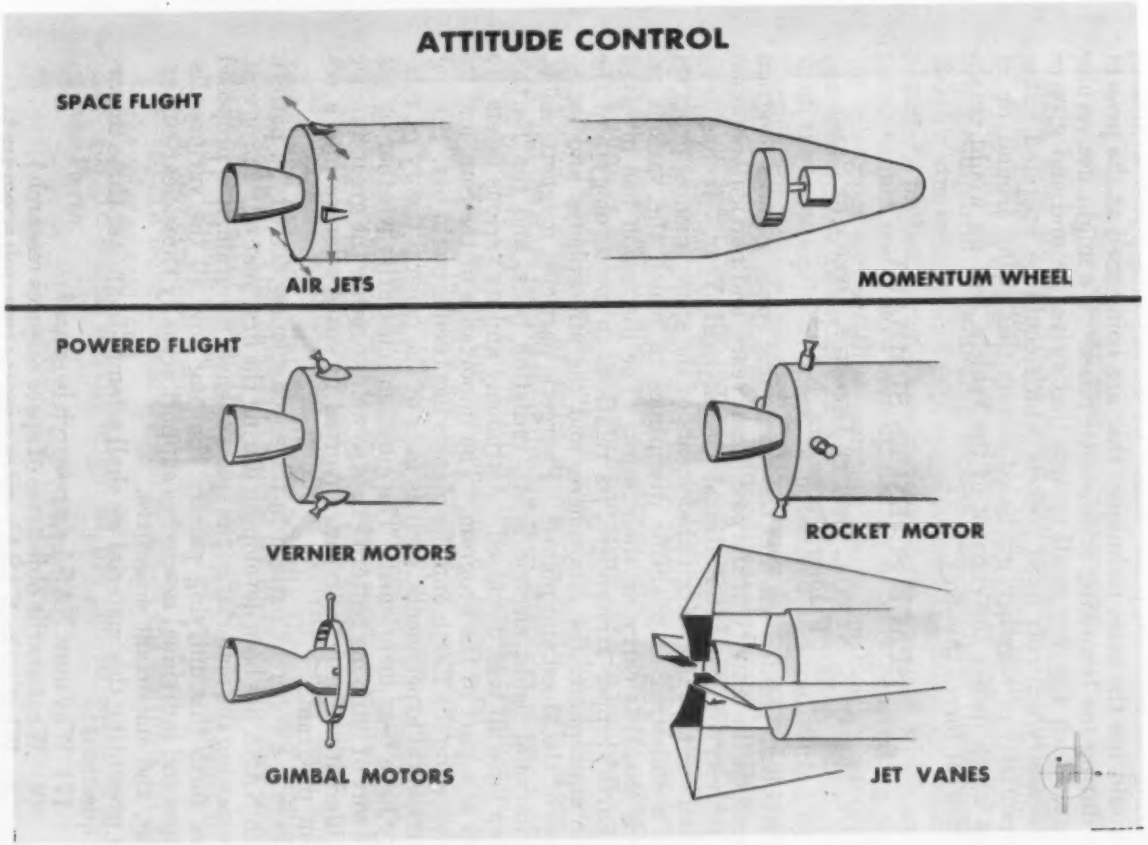

ATTITUDE CONTROL
SPACE FLIGHT
AIR JETS
MOMENTUM WHEEL
POWERED FLIGHT
VERNIER MOTORS
ROCKET MOTOR
GIMBAL MOTORS
JET VANES

FIGURE 29

the chart we have a motor and a wheel. If we speed up the wheel in one direction, there is going to be reaction which is going to make the vehicle turn the other way. We can also do this about all three axes.

During the terminal phase where we do have the power available, we would use the same techniques that are being used at the present time during the launching or injection phase. We might use vernier rockets, which are very small rockets that swivel around and give us the necessary control; fixed rockets which could be operated either differentially or together, gimbaled motors that swing around, or jet vanes which deflect the exhaust of the vehicle, and we would obtain our control forces this way.

SPACE SCIENCES SUMMARY

DR. HOMER E. NEWELL, DEPUTY DIRECTOR, OFFICE OF SPACE FLIGHT PROGRAMS, NASA

It has been pointed out that the developing space sciences program is based on the activity of the past dozen years, and particularly upon the activity of the International Geophysical Year. It has been pointed out that the principal elements of the space sciences program were a collection of scientific disciplines in which the various research scientists carry on their work. The discussion has involved the Earth's upper atmosphere, its relations to meteorology and the lower atmosphere, the ionosphere, and the atmospheres and ionospheres of the Moon and planets. Energetic particles, magnetic fields, gravitational fields, electric fields, radiation belts, and the Earth's aurora have all been discussed. Astronomy and its various facets are listed as a part of the program. The importance of the Sun, and its influences on the Earth and the planets has been brought out. Special fundamental experiments, such as tests of the general theory of relativity have been mentioned. The question must arise whether or not some sort of unifying pattern exists to weld together the great number of different scientific activities involved in space sciences into a coherent program.

There is a coherent pattern in the space sciences activity, a pattern which NASA has been developing during the first year of its program. In reviewing the material on the space sciences program, it is proposed to set forth this unifying pattern showing how all the various disciplines and individual researches support actually three clear-cut, exciting, and important objectives.

In presenting this material we shall attempt to answer three important questions:

(1) Why must NASA do research in space?
(2) What are the objectives of space sciences research?
(3) What is the NASA's space sciences research program?

WHY DO SPACE RESEARCH?

Now, why must NASA do research in space? The many reasons can be summarized by the observations that such research contributes materially to each of the eight objectives enumerated by the Congress in the National Aeronautics and Space Act of 1958 and, in fact, con-

stitutes the very first objective: "The expansion of human knowledge and phenomena in the atmosphere and space." Furthermore, before man ventures into this new and hostile environment of radiation belts, solar winds, cosmic radiation, and meteorites, we must learn enough about this environment to insure man's safety.

NASA RESEARCH OBJECTIVES

Next, what are the NASA space sciences research objectives? In the past, man was limited to observations which could be made at or near the surface of the Earth. Now the scientist can send his measuring equipment on sounding rockets and satellites throughout the Earth's atmosphere, and into space beyond the Moon on lunar and planetary probes. Even those regions of the universe which instruments cannot reach have been opened up to more penetrating study; for telescopes and satellites coursing above the Earth's atmosphere can observe the radiations in all of the wave lengths which arrive from the vast depths of space. Unobscured and undistorted by the Earth's atmosphere, these radiations may be expected to reveal a hitherto inaccessible wealth of information about the universe.

Seizing upon the new opportunities, scientists the world over are busily investigating a wide range of phenomena. The geophysicist is using sounding rockets and Earth satellites to study the properties and behavior of the Earth's atmosphere, ionosphere, magnetic field, auroras, and other phenomena in space close to the Earth. Cosmic rays, radiation belts, and the solar wind are under intensive investigation thousands of miles above the Earth. The Moon, the Sun, and the stars receive their due share of attention. Cosmic experiments to study gravity and relativity theory, to observe physical processes and materials in the environment of space, and to probe the mysteries of life in space are in preparation. Manned flight away from the Earth into the hostile environment of space is imminent. In support of this worldwide quest for knowledge and experience, hundreds of sounding rockets and more than a dozen satellites and space probes are to be fired each year for the foreseeable future.

At first glance, this broad range of activities may seem disconnected and random. But in all this activity there is one simple, coherent pattern. One clear-cut, concise set of objectives ties together and motivates all of this activity. These objectives are:

(1) To understand the nature of the control exerted by the Sun over events on the Earth;

(2) To learn the nature and origin of the universe, including the solar system; and

(3) To search for the origin of life and its presence outside the Earth.

IMPORTANCE OF THE SUN

Let us consider the first objective. The Sun affects every aspect of human activity. If its radiation were to increase or decrease by a small fraction of 1 percent, our present mode of existence would undergo marked changes. Knowledge of the Sun and its influence on the Earth has direct bearing on our daily activity and on our very existence.

Actually, we know that the total solar energy output does not, and should not be expected to, change appreciably. It is for this reason that the solar energy reaching the Earth's surface per square centimeter per minute is called the solar constant. It is this energy in the visible and infrared regions of the spectrum which furnishes the driving power for our winds, storms, and the other manifestations of weather.

But one small part of the Sun's energy does undergo important fluctuations. This part comprises the gusts of X-rays, ultraviolet light, and charged particles which are emitted from the Sun at times of unusual surface turbulence. The radiations travel at the speed of light, reaching the Earth some 8 minutes after leaving the sun. They are absorbed in the higher levels of the atmosphere, well above our "weather sphere," and produce heating, chemical reactions, and electrical charging of the very thin air. It may be said that they give rise to a sort of upper atmospheric weather whose storms produce heating, chemical reactions, and radio blackouts. The charged solar particles travel at the more modest speed of some 1,000 miles per second, reaching the earth in 1 or 2 days. Upon arrival, they are seized by the Earth's magnetic field and funneled into the polar latitudes, producing magnetic field storms, modifying the radiation belts, augmenting the auroral displays, and producing longer lived radio and telephonic communications breakdowns.

One of the most exciting chapters in the history of Sun-Earth relationships concerns the discovery by James Van Allen of the radiation belts which bear his name. These belts consist of charged particles which are trapped and guided by magnetic lines of force many thousands of miles above the Earth's surface. Although the possible radiological effects of these particles are well known, their geophysical role in transferring energy from the Sun to the Earth, accompanied by heating, auroras, and communications disturbances, may well prove to be more significant.

Experimental evidence obtained during 1959 shows the importance of the Van Allen belts in Sun-Earth relationships. Pioneer IV, launched in March after 5 days of unusually intense solar and auroral activity, detected a belt population some 10 times greater than that observed by Pioneer III during a period of solar quiet. In October, Explorer VI radioed back counting rates 5,000 times lower than those of Pioneer IV; but several weeks later, after some intervening solar activity, Explorer VI counter showed a return of the particle population nearly to its Pioneer IV level.

These fragmentary measurements have led to strong disagreements among the scientists themselves concerning the interpretation of the results and their geophysical importance. Consequently, it is important to measure the populations of such energetic particles over long periods of time and to many tens of thousands of miles from the Earth. One entire satellite to be launched in 1961 will be devoted to the observation of these trapped particles, using more complex detectors which will separate the particles by type and by energy. Particularly important will be the first measurement of the very low energy protons (hydrogen nuclei) having energies of less than 10,000 electron volts, which is only half the energy of the charged particles in the average home TV picture tube. Due to their potentially large

population, such particles may even be dominant in producing geophysical effects.

The second approach to the measurement of charged particle activity is the use of a space probe in orbit around the Moon, to detect the clouds of solar particles as they sweep across the Moon's orbit, and, in cooperation with measurements from an Earth satellite, to measure the velocity of the solar particles. Still another approach to be followed in 1960 is the rocket launching of recoverable film, or nuclear emulsions, into the polar atmosphere during unusual solar activity, so that the responsible particles may be identified by studying their photographic tracks. Such identification is as positive as that of an individual by his fingerprints.

Such effects have a practical aspect. It has been suggested that the arrival of large numbers of solar particles may trigger major weather distrubances. For example, on February 10, 1959, a large solar flare was followed by magnetic storms, radio disturbances, a red aurora visible as far south as Washington, record high temperatures in the Arctic, and freezing snow throughout large areas of the South. Although this one event could have been coincidental, a study of weather statistics for other years has shown a definite correlation between magnetic storms and rising polar temperatures 5 days later. Tree rings and wheat price index both show an 11-year cyclic weather variation, corresponding to the sun spot activity cycle. More knowledge of such phenomena could lead to the future use of data transmitted from a distant satellite observatory to predict the arrival of a cloud of solar particles in time to light the smudge pots in Florida.

The importance of the Sun to man, and the immediate value of the knowledge of Sun-Earth relationships, is clear. But, underlying such relationships is an even more fundamental matter, that of the nature of the entire universe. Science is based on the assumption that all activity is governed by universal laws which apply both near at hand and in the remotest part of the universe. These laws form the basis for the origin and development of living matter.

THREE BASIC FORCES

All the achievements of science in the last century have been applied to the development of a remarkable description of the universe and its elementary constituents. The development begins with the neutron, proton and electron; these are the fundamental building blocks of the universe. Neutrons and protons are bound together tightly to form the atomic nucleus. Atoms consist of electrons bound to the nucleus and circling around it at some distance, like a planetary system in miniature. Atoms combine to form molecules, which in turn are cemented together to form visible matter as we know it. Our Earth is a collection of such matter, circling around the Sun along with the eight other known planets. The Sun is one of the 100 billion stars of our disc-shaped galaxy whose cross section we know as the Milky Way. In turn, the galaxies tend to collect in huge clusters which together make up the universe. This entire hierarchy is built on three basic forces:

(1) Nuclear force, the most powerful force known, which clamps together the nucleus of the atom so tightly that one cubic

inch of nuclei (such as is found in white dwarf stars) weighs 1 billion tons.

(2) Electromagnetic forces, which bind electrons to nuclei, atoms into molecules, and molecules into gross matter. These forces are some 100 times weaker than nuclear forces.

(3) Gravitational force, which gives man weight and holds the solar system together. This force is 10^{40} times weaker than the nuclear force.

The weakness of the gravitational force can be illustrated by the smallness of an electromagnet which will lift a 1-pound iron bar, compared with the tremendous size of the earth which generates 1 pound of gravitational force on the iron.

Strangely enough the formation and evolution of stars depend upon the interplay between the weakest and strongest of these forces. Initially, stars are probably formed out of condensation of the interstellar dust in space. Once begun, gravitational attraction accelerates the condensation process until the pressure and temperature at the center are high enough to initiate a thermonuclear reaction whose heat prevents further attraction. The rest of the star's life history depends only on its initial mass and on the relative amount of different elements present; i.e., its chemical abundance. The determination of this chemical abundance of stars is one of the most basic problems in the study of stellar evolution.

Perversely enough, the light which contains the best information on chemical abundance on stars is beyond the visible portion of the spectrum in the ultraviolet; but such wavelengths cannot penetrate the Earth's atmosphere. Thus, for the first time, man can obtain this vital information from an observatory located on an artificial or natural Earth satellite. The very first ultraviolet experiments, flown by scientists of the U.S. Navy in rockets, disclosed many sources of ultraviolet light, some at locations where there is no visible emitter of light. The nature of such ultraviolet sources is still a mystery. Their further study from an orbiting astronomical observatory is an objective of the highest scientific priority which may be expected to produce new information concerning the structure of the universe.

Just as stars may have formed by the condensation of interstellar matter, so planets may have formed by the condensation of smaller pockets of matter left over from the stellar formation. If this condensation theory is the correct one, then planets such as ours must be very commonplace in the universe. On the other hand, it is possible that our planets were born catastrophically, in a rare collision between our Sun and a second star. Since the probability of such a collision is extremely small with the existing stellar population, the catastrophic theory implies a small probability of other planets in the universe, and a correspondingly small chance of life existing outside of our solar system.

IMPORTANCE OF THE MOON

If we can determine what the temperatures of the Moon and planets were at the time of their formation, we will have gone far toward discriminating between the condensation and catastrophic theories of the origin of the solar system. For if these planets were formed by

the cooling of hot masses of solar gas, they must have passed through a molten phase; while if they were formed by the condensation of relatively cool gas or dust, they may never have existed in the molten stage. This is particularly true of the Moon, which is small enough so that the heat produced by decay of radioactive uranium can be lost to its surface rapidly enough to keep the temperature below the melting point. In this respect, the Moon is of greater interest than either Mars or Venus.

Another reason for concentrating on lunar observations is the uniqueness of the Moon as the only major accessible body whose surface has been unchanged for a major portion of its life, some 3 billion years. This is due to the combined lack of mountain building and lack of erosion by air or water.

Thus, our first need is to come close enough to read nature's handwriting on the lunar surface. Television cameras in orbit about the Moon or en route to a crash landing can radio back detailed information of the lunar surface characteristics, while observations of a lunar satellite orbit can detect whether or not the Moon has a "raisin bread structure" of iron chunks embedded among lighter rock, which would indicate a process of accretion from small cool masses. Television reconnaissance can also be used to select a location for the first soft lunar landing, and to obtain information concerning the nature of the surface.

Once a soft landing is feasible, instruments such as the seismograph can be placed on the lunar surface to detect moon quakes produced internally or by meteorite impact. A gravimeter can measure minute changes in the lunar shape produced by the Earth and Sun, thus measuring the elasticity and viscosity of the Moon's interior. Measurement of the surface heat flow and radioactivity would fix the temperature history of the Moon within narrow limits, thereby further defining its mode of initial formation.

Again we find a coherent pattern in our search for the origin of the universe. Experiments on the interaction between radiation and matter, on relativity theory, and on gravity, lead to an understanding of the working of the universe today. Exploration of the Moon and planets, together with observations of the Sun and the rest of the universe, will help determine how the universe began and how its stars and planets were formed. All of these diverse activities and many others contribute to the one great inspiring objective: to understand the universe of which man is such an infinitesimal, but important, part.

SEARCH FOR LIFE OUTSIDE OF EARTH

One of the most exciting possibilities of space research is the opportunity to search for life outside of the Earth and its atmosphere. Were one to discover life forms on another planet like Mars or Venus, the philosophical implications would be tremendous. Working on the Earth and in the laboratory, the bioscientist has progressed toward an understanding of how material life may have formed on Earth. Our understanding of the origin of life might make gigantic strides forward if we could discover and study, at the same time, different life forms that have developed and currently exist under different conditions.

The primitive atmospheres of Venus and Mars were doubtlessly similar to ours, but not identical with it, and the development of life on these planets, if it did occur, may be presumed to have proceeded along somewhat different lines.

The practical consequences of this research of planetary biology will require a longer time to develop, because the acquisition and interpretation of the basic facts are both very difficult. But in the long run, such research can be expected to have a greater influence on human welfare than any other area of the space sciences program. Most diseases today are regarded as essentially metabolic, that is, as due to aberrations in the normal pattern of molecular interactions. It is precisely these interactions which we hope to understand better through our biological studies of other planets.

Mars and Venus are the solar planets, other than the Earth, which appear to offer the greatest probability of the development of life. The manned landings required for thorough exploration of these planets will not be possible for many years to come. Meanwhile, a progressive program of instrumented planetary explorations will be undertaken as rapidly as the necessarily sophisticated guidance, communications, and soft landing techniques become available.

At present, balloons capable of lifting heavy infrared spectroscopes to altitudes of 10 to 20 miles above the Earth can acquire valuable information on Venus and Mars atmospheric constituents and on the nature of some Martian surface compounds. During 1959, an Office of Naval Research sponsored experiment discovered water vapor in the atmosphere of Venus. Early space probes will develop long range communications techniques, measure the characteristics of the interplanetary environment, and observe those features of the planets, such as their magnetic fields and radiation belts, which may be expected to extend into space many times the planetary diameter.

RESULTS AND PLANS FOR NASA RESEARCH PROGRAMS

During the past year, as shown in table 1, a number of important scientific discoveries have already resulted from the NASA space

TABLE 1.—*Recent discoveries in space sciences*

Area	Discovery	Questions raised
Radiation belts	Outer belt extent and intensity fluctuates	Causes.
	Correlation with solar activity	Mechanism.
	Complex structure	Explanation.
Magnetic field	Deviations from expected values	Source.
	Fluctuations with time	Causes.
Upper atmosphere	Very strong wind shears at 70 to 100 miles	Cause.

sciences program. With regard to the Van Allen radiation belts, it has been discovered that the extent and intensity, particularly of the outer belt, fluctuates over a very wide range. These fluctuations show a distinct correlation with activity on the Sun, and a complex structure which varies with time. As usually occurs in scientific research, such discoveries raise as many or more questions than they answer.

The last of the Vanguard satellites has disclosed deviations from their expected values of the Earth's magnetic field, and some fluctuations in the measured magnetic field intensity with time. Again, such results raise questions regarding the sources and causes of these deviations and fluctuations. It should also be recalled that three successful satellites were launched during the latter half of 1959 and, since 6 months to a year is usually required for thorough data analysis, most of these data will be translated into new discoveries in 1960. If all goes as planned, Explorer VII will continue to radio back data for another 9 months.

Several important results also resulted from the NASA sounding rocket program during 1959 (table 2). Perhaps the most notable of

TABLE 2.—*Scientific sounding rocket launchings, 1959*

Date	Vehicle	Experiment	Comment
August	Nike-Asp	Sodium vapor, dawn	High winds, 400 to 500 knots, 150 kilometers.
September	Aerobee-150 (2 rockets)	Ionosphere measurements; instrument development.	Successful tests of new satellite instrumentation, new ionospheric data.
November	Nike-Asp	Sodium vapor, twilight	Powerful wind shears around 110 kilometers.

these resulted from the Wallops Island launchings of rockets carrying sodium, which were visible over a wide area of the east coast. The resultant sodium vapor clouds showed very strong wind shears at altitudes between 70 and 100 miles, and wind velocities at slightly higher altitudes in excess of 400 miles per hour. During 1959, there were also several very successful tests of new satellite instrumentation for direct measurements of the structure of the charged region of the atmosphere which is called the ionosphere.

Table 3 summarizes the planned NASA rocket launchings through the end of fiscal year 1961. Since each sounding rocket is generally

TABLE 3.—*Sounding rockets*

	Fiscal year 1960		Fiscal year 1961			
	3d quarter	4th quarter	1st quarter	2d quarter	3d quarter	4th quarter
Atmosphere	3	4	4	4	3	3
Synoptic atmosphere	2	2	9	9	6	6
Ionosphere	2	2	2	2	2	2
Energetic particles	2	6	2	1	3	2
Magnetic field		5	1		2	3
Astronomy	6	8	8	8	6	6
Special	10	3	3	1	2	2
Total	25	30	29	25	24	24

devoted to only one or two scientific disciplines, it is convenient to divide them according to their scientific purpose. The planned level of activity of approximately 100 sounding rockets per year is only slightly less than that reached during the peak of activity during the 18-month International Geophysical Year, when 200 sounding rockets were launched by this country.

During 1959, four scientific satellites were launched successfully (table 4). Two of these utilized the Vanguard launching vehicle, one

TABLE 4.—*Scientific satellites, 1959*

Name	Month	Vehicle	Experiments
Vanguard II	February	Vanguard	Cloud cover.
Explorer VI	August	Thor-Able	Radiation belt, magnetic field, micrometeorite, radio propagation, cloud cover.
Vanguard III	September	Vanguard	Magnetic field, solar X-rays.
Explorer VII	October	Juno II	Composite radiation.

the Thor-Able combination, and one the Juno II vehicle. These launchings completed our participation in support of the International Geophysical Year by means of scientific satellite research.

During 1960, the Juno II scientific satellite program will be completed with the planned launching of four additional satellites (table 5). The first and fourth of these missions represent follow-on studies

TABLE 5.—*Juno II scientific satellites*

Fiscal year:	*Mission*
1960: 3d quarter	Radiation belt studies.
1961:	
1st quarter	Ionosphere properties.
2d quarter	Gamma and cosmic rays.
Do	Ionosphere beacon.

to earlier exploratory experiments. The second and third of these missions are first exploratory experiments.

The five scientific satellites listed in table 6 are planned to be launched with the use of the Thor-Delta vehicle system over the next

TABLE 6.—*Delta scientific satellites*

Fiscal year:	*Mission*
1961:	
2d quarter	Solar spectroscopy.
3d quarter	Radiation belt studies.
1962	Atmospheric structure.
1962	Geodetic flashing light.
1962	Ionosphere topside sounder.

2 years. The last three of these missions represent first exploratory satellite experiments in their respective scientific fields, and will be launched in orbits across the polar regions.

By fiscal year 1962, it is expected that the solid-propellant Scout satellite launching vehicle will have been developed for routine use in the scientific satellite program. This vehicle will be put to frequent use in support of our international cooperative program in space sciences (table 7). Like the Delta satellite system, most of the

TABLE 7.—*Scout scientific satellites*

Fiscal year:	*Mission*
1962	International.
1962	Polar ionosphere studies.
1962	International.
1962	Polar radiation studies.
1963	International.
1963	Polar atmospheric structure.

Scout scientific satellites will be launched in orbits over the Earth's polar regions, with the exception of those satellites primarily devoted to the astronomical program.

The satellites which have been discussed thus far are all limited to maximum payload weights of the order of a few hundred pounds. Beginning in 1962, the Atlas-Agena and Thor-Agena vehicle systems will be capable of placing into orbit scientific satellites weighing 1,000 pounds and more. Two such satellites are planned to be launched into orbits over the polar regions of the Earth for various geophysical studies, as shown in table 8. A Thor-Agena satellite will be used in

TABLE 8.—*Agena scientific satellite*

Fiscal year	Booster	Mission
1962	Thor	Polar geophysics.
1963	Atlas	Geophysical observatory.
1963	Thor	Sun-Earth relations.
1963	Atlas	Astronomical observatory.

a relatively low altitude orbit of several hundred miles, while an Atlas-Agena will be used in a highly eccentric orbit reaching many tens of thousands of miles from the Earth's surface at its highest point. The other two Agena satellites will be launched into orbits of relatively low inclination to the Equator, one to correlate relations between solar activity and phenomena in the Earth's atmosphere, and the other to make astronomical observations using a highly precise stabilized astronomical platform. This last satellite will weigh several tons.

During 1959, the first U.S. space probe to escape the Earth's gravitational control and go into orbit about the Sun was launched on March 3. This payload produced valuable information regarding the radiation belts, and was tracked to a distance of 407,000 miles from the Earth (table 9).

TABLE 9.—*Space probe, 1959*

Pioneer IV.
Mar. 3.
Juno II vehicle.
Energetic particles experiment.
Communications tests.
Tracked for 82 hours to a distance of 407,000 miles.
Now in orbit about the Sun.

During the next 2 years, in addition to their use in the scientific satellite program, four Scout vehicles will be used to launch scientific probes which are intended to reach altitudes of from 5,000 to 10,000 miles. These probes are listed in table 10.

TABLE 10.—*Scout scientific probes*

Fiscal year:	*Mission*
1961, 2d quarter	Ionosphere structure.
1961, 3d quarter	Nuclear emulsion recovery.
Do	Ionosphere structure.
1962	Outer atmosphere winds.

These comparative short-range Scout probes which fall back to the Earth should be distinguished from the longer range lunar and inter-

planetary probes which are scheduled during the same time period, as shown in table 11. Initially, relatively lightweight space probes

TABLE 11.—*Lunar and interplanetary probes*

Fiscal year	Vehicle	Mission
1960, 3d quarter	Thor-Able	Interplanetary environment and communications tests.
1961:		
1st quarter	Atlas-Able	Lunar orbiters.
2d quarter	do	
Do	Delta	Interplanetary plasma and field.
4th quarter	Atlas-Agena	Interplanetary environment technological development.
1962	do	
1962	do	Lunar surface properties.
1962	do	
1962	do	

will utilize the Thor and Atlas boosters with the Able and Delta upper stage systems, for preliminary research on the interplanetary environment and for tests of long-range communications. Beginning in 1961, the heavier Atlas-Agena system will also be available for this important program. The first two Atlas-Agenas will be used for the twin purposes of measuring the interplanetary environment and for developing the necessary technology for more advanced missions. The last three of these vehicles will concentrate on the measurement of the surface properties of the Moon.

In fiscal year 1963, using the Atlas-based Centaur vehicle system, we will be ready for our first attempts at probes toward the planets Venus and Mars. The objectives of technological development for later, more advanced missions and an investigation of both the planetary and interplanetary environment will be served by these missions.

In summary, the space sciences program over the next several years will include approximately 100 sounding rockets per year, some 9 satellites and Scout probes, and approximately 4 deep space probes for lunar and planetary explorations (table 12). Nearly half of the

TABLE 12.—*Space sciences vehicle summary*

	Fiscal year 1960	Fiscal year 1961	Fiscal year 1962	Fiscal year 1963
Sounding rockets	55	102		
Scientific satellites and Scout probes	[1] 4	9	9	5
Lunar and planetary explorations	[2] 2	4	4	2

[1] Includes 3 in orbit.
[2] Includes 1 launch failure.

requested funding in the space sciences area will be devoted to lunar and planetary explorations, while the sounding rocket program will require less than 10 percent of the total.

II. APPLICATIONS PROGRAMS

METEOROLOGICAL SATELLITES

By Dr. Morris Tepper, Chief, Meteorological Satellite Program, NASA

Man lives at the bottom of a vast "ocean" of air. This ocean covers the entire globe and extends upward with diminishing density. This atmospheric ocean is in constant motion, its properties changing constantly. Earlier scientists soon recognized that particular atmospheric motions produced particular weather patterns and so it became necessary to observe and describe the basic atmospheric motions.

The first weather charts covered an area of only a few thousand square miles and were restricted to surface observations taken more or less simultaneously at prescribed times. The more these charts were studied and used for forecasting weather, the larger was the area covered by observations and the stronger became the realization that knowledge of the interaction of atmospheric processes vertically and horizontally over hemispheric dimensions was required in order to understand fully meteorological motions and their time variations. Out of this realization there developed the existing world radiosonde network (shown in fig. 30) covering many land areas, islands, and oceanic shipping routes. Each station shown in this network is an upper air sounding station where the atmospheric pressure, temperature and moisture are sampled vertically to about 100,000 feet elevation, twice, and at places, four times daily. Recently, with the advent development and use of the sounding rocket, measurements are also being made from time to time of the upper 1 percent of the atmospheric mass, beyond the reach of the radiosonde balloon.

The distribution of observing stations in the radiosonde network is such that only a very small portion of the atmosphere can be sounded by this conventional meteorological sounding technique. The observing stations are by and large manned and consequently are located primarily in areas where year-round residence is feasible. Thus, large storms can reside undetected for days in many desert, polar, and oceanic areas where there are very few stations, if at all. The oceanic areas of the Southern Hemisphere are particularly devoid of upper air sounding stations. Yet, information from this region is highly desirable since by virtue of the global nature of the atmospheric flow, it is quite probable that atmospheric information from the Southern Hemisphere would be most helpful in explaining events in the Northern Hemisphere.

Even in the areas where there appears to be a more dense distribution of observing stations, our information is often inadequate, particularly with regard to the existence and movement of smaller scale storms. In these areas, storms of limited areal extent may develop and produce significant weather without being properly recognized by conventional techniques. The transient and ofttimes extremely violent storms may strike an unsuspecting locality with little possibility of timely warning.

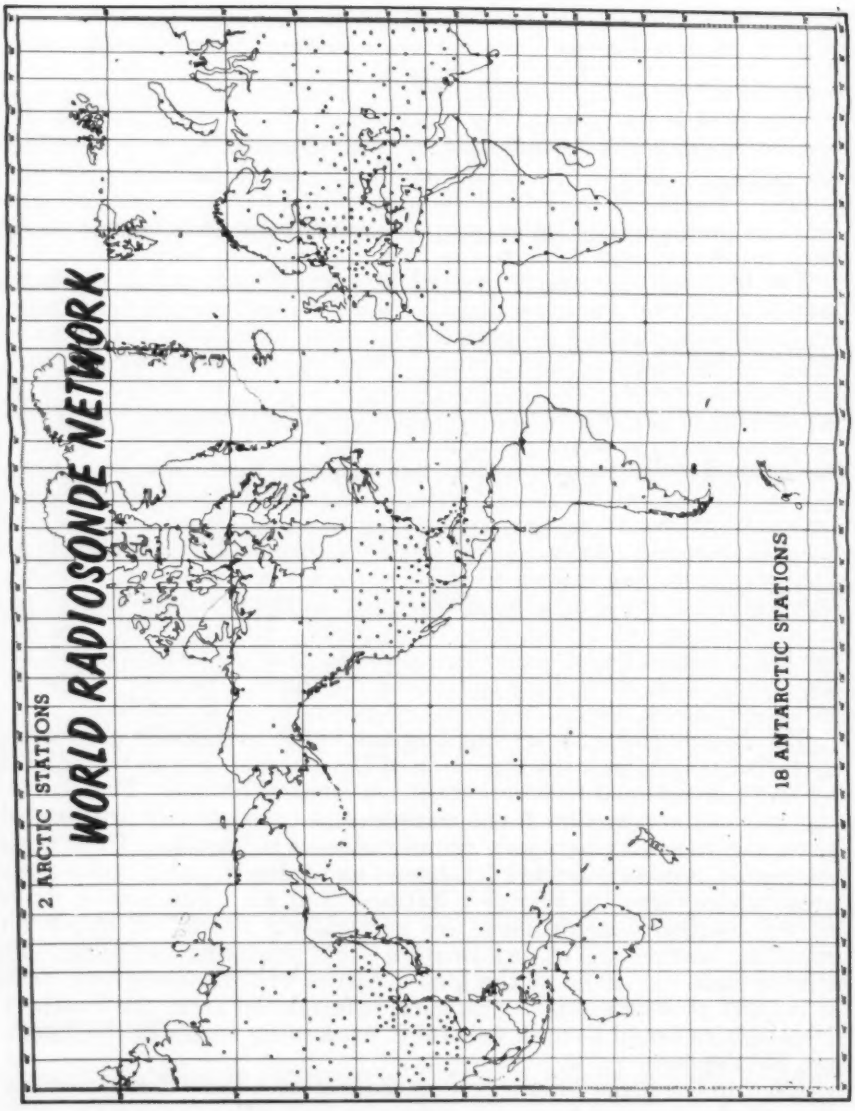

WORLD RADIOSONDE NETWORK
2 ARCTIC STATIONS
18 ANTARCTIC STATIONS

FIGURE 30

SATELLITES WILL ALLOW CONTINUOUS STORM TRACKING

By the use of satellites orbiting about the Earth, man will obtain a downward look at clouds—those everchanging manifestations of atmospheric motions, which can be used to identify and pinpoint storms and fair weather areas. With a proper distribution of meteorological satellites orbiting about the Earth, it should be possible to keep continual track of almost every storm on Earth, to note the birth of new storms, and the death of old ones.

No less important than the obvious practical benefits of satellites for storm identification and short-range weather forecasts will be the contribution to the basic knowledge of atmospheric physics; for example, the measurement of global distribution of the net radiant energy absorbed and emitted by the Earth-atmosphere system—quantities that have never been measured. Since "weather" results from winds attempting to equalize the nonuniform distribution of net radiant energy received from the sun, it is important to keep an accurate account of the global distribution of the basic radiant energy which drives the atmospheric heat engine. This energy budget when measured over long periods of time will not only be useful in interpreting basic knowledge of the atmospheric processes but might also assist in formulating a new system of long-range weather forecasts and in anticipating climatic changes.

Present meteorological forecasts cannot be materially improved until we have a better understanding of atmospheric processes and are able to obtain global coverage in our observing program. Satellites provide the only practical means of obtaining meteorological observations on a global basis. The new types of data to be obtained from satellites in conjunction with basic research using these data will undoubtedly lead to a significant increase in our understanding of the atmosphere.

In order to apply the dynamical prediction equations to the forecasting of atmospheric motions, the meteorologist develops atmospheric "models." These models include assumptions concerning the nature and behavior of the atmosphere and statements of initial conditions. It follows that the more realistic these assumptions and initial conditions, the more realistic will be the solutions. This involves accurate global observations of clouds, of cloud movement, and of solar and infrared radiation to establish the heat sources and sinks in addition to the distribution of water vapor, temperature and pressure. Among other things, these measurements will be useful in improving our knowledge about the "initial" conditions needed for the forecasting models.

In order to improve our scientific understanding of the nature of the atmosphere, and in order to provide proper initial conditions for forecasting, and in order to detect existing storms, an observation tool is required which will observe and measure the atmosphere "everywhere, all of the time."

The meteorological satellite offers to the meteorologist for the first time an observing platform equal in scope to the global extent of the atmosphere, but which at the same time can provide the resolution required for identification of local weather events.

FIGURE 30

53795 O—60—pt. 2——6

OBJECTIVES

The overall objective of the NASA meteorological satellite program is to establish a meteorological satellite capability for worldwide coverage which would provide those observations required by the meteorologist in order to increase his understanding of atmospheric processes and improve his ability to predict the weather. Satellite observations being considered include those of cloud cover, storm location, precipitation, temperature, wind direction, heat balance, water vapor and other constituents, and some extraterrestrial observations related to the Earth's atmosphere.

To achieve this objective will require: (*a*) the development of Earth-stabilized satellites for polar orbits of 500- to 1,000-mile altitudes and "stationary" satellites for equatorial orbits of 22,000-mile altitudes; (*b*) the development of suitable onboard detection equipment, including television, infrared detectors, radar, spectrometer, and detectors of short wavelength radiation; and (*c*) the development of adequate data storage, handling and communications equipment and techniques.

The long-range objective is to develop the principles of a system of instrumented orbiting satellites and communications network by means of which worldwide meteorological information may be transmitted to the National Meteorological Center of the Weather Bureau for its operational use.

Since the NASA is responsible for the national meteorological satellite program, it must develop a system which will meet the data requirements of the two prime users of these data—the U.S. Weather Bureau and the Department of Defense. To insure that NASA is responsive to the interests and needs of the Weather Bureau and DOD in this program, there has been established a Joint Meteorological Satellite Advisory Committee (JMSAC) with representation from the three organizations—DOD, WB and NASA. This committee (*a*) considers the national requirements in the meteorological satellite program, (*b*) serves as a medium of interchange of information among the members and (*c*) assists wherever possible and appropriate in specific operating programs.

MEANS FOR REACHING THE OBJECTIVES

A comprehensive program of instrumentation and systems development, satellite launchings, collection and processing of satellite and basic and applied meteorological research is planned to meet the above objectives.

The Meteorology Branch of the Satellite Applications System Division, Goddard Space Flight Center, has been organized to provide the technical and engineering direction required in payload instrumentation, vehicle and payload integration, communication and data handling.

A meteorological satellite research group is being established in the Weather Bureau to process and analyze meteorological satellite data, to assist in the design of experiments and instrumentation, to utilize the resulting satellite data to increase our knowledge of the atmosphere, and to develop techniques of applying satellite data to meteorological problems.

NASA is strongly dependent on the vast industrial potential of the United States for providing the required development and fabrication of the flight hardware, and on many industrial and university meteorological research groups in assisting in the analysis and interpretation of the data.

The following are the parameters, important to meteorology, which will be measured from satellites:

(1) Cloud observations, both day and night, on a global basis.

(2) The heat budget of the Earth and atmosphere.

(3) Indirect measurements of the temperature structure and composition of the atmosphere.

(4) The solar radiation spectrum and particle emission and their changes with time.

(5) Radar coverage giving worldwide precipitation and perhaps cloud structure.

Other measurements on a global basis such as thunderstorm distribution are desired by meteorologists, and techniques are being developed for suitable satellite instrumentation. In some cases, no techniques for obtaining important measurements by means of satellite instrumentation have been developed as yet, e.g., the surface pressure, atmospheric winds in cloudless regions, vertical density profile, etc.

CLOUD COVER MEASUREMENTS

Cloud measurements on a global basis from the satellite are obviously most important to meteorology. They indicate regions of weather activity and ofttimes how severe this weather might be. Still, there are many problems involved in the proper interpretation of cloud pictures since these pictures present a new kind of data previously unavailable to the meteorologists. In order to develop techniques of analysis and photointerpretation by means of which it will be possible to extract significant meteorological information from such photographs, meteorologists have been carefully studying all available photographs taken from high altitudes.

For example, during the past year there have been several instances where a camera containing film was placed in a recoverable nose cone of an Atlas or Thor launch vehicle. Although the initial and primary purpose for the camera was nonmeteorological, it turned out that some very good pictures of the Earth's cloud cover emerged as a byproduct. In figure 31 in the upper left-hand corner is a mosaic of several photographs taken at about 300 nautical miles elevation during the flight. The clouds were transcribed onto a map and are shown as shaded areas on the accompanying map. Superimposed on the chart is the weather situation for the day. There is remarkable correspondence between the major cloud areas and the major weather storm regions—as shown by the stationary front, the equatorial trough and the easterly wave.

This very preliminary analysis was performed by the scientists of the General Electric Co.—the company directly concerned with the nose-cone experiments. However, there is a considerable amount of additional detail on this photograph. Research is needed to determine the relationship of these additional detailed features to the atmospheric picture as presented by other meteorological data. In

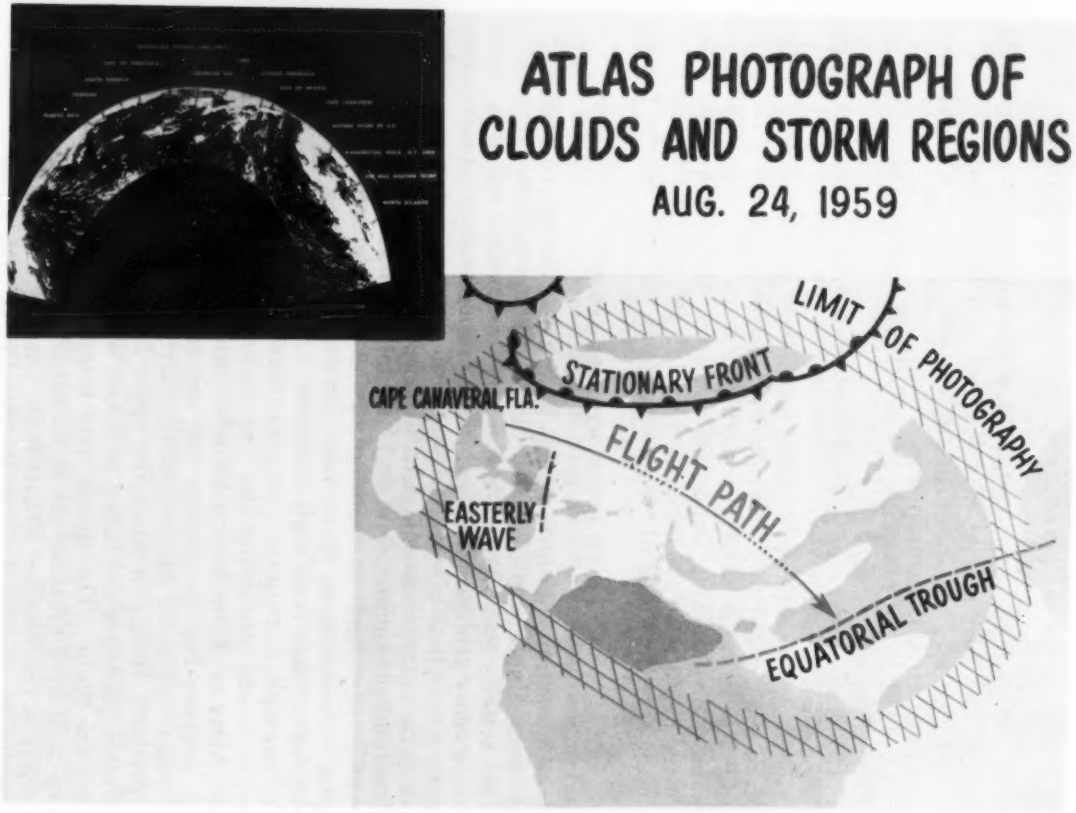

ATLAS PHOTOGRAPH OF
CLOUDS AND STORM REGIONS
AUG. 24, 1959
LIMIT OF PHOTOGRAPHY
STATIONARY FRONT
CAPE CANAVERAL, FLA.
FLIGHT PATH
EASTERLY WAVE
EQUATORIAL TROUGH

FIGURE 31

general, however, cloud measurements will probably be the first to be used in meteorological forecasting.

For widest meteorological applications it will be necessary to obtain cloud pictures both day and night over the whole world with various resolutions depending on the scale of the phenomenon of interest.

Such measurements will tell us at regular intervals the worldwide distribution of cloud type, cloud amount, and cloud patterns. Considerable meteorological information is contained in such data. For example, different types of storms can be detected by the resulting types and distribution of clouds. In many instances the orientation of cloud elements depicts the wind direction at cloud altitude. It may be possible to develop techniques for determining cloud movement and from this infer the wind speed. The type and structure of clouds infer the stability in the atmosphere and the type of airmass in which the clouds are located.

The cloud data can be obtained in several ways. The clouds can be observed with high resolution photocells which scan the Earth. Snapshot pictures can be obtained using systems similar to television or film cameras. Infrared sensors can be used for both day and nighttime cloud measurements, and the three-dimensional structure of clouds both day and night may be measured by very high frequency radar.

The cloud-cover experiment on Vanguard II (see fig. 32) is an example of the use of photocells on a spinning satellite to scan the Earth and clouds and obtain cloud-cover information. A wobble developed during the launch of this satellite, with the result that there is appreciable difficulty in reducing the data. From the Vanguard II experiment it is obvious that this system can be used only on a satellite which has very well controlled orientation and motions. The snapshot-picture approach has been utilized on the Tiros I satellite.

Both the Vanguard and Tiros experiments have several shortcomings in meeting the meteorological requirements for cloud observations. These spin-stabilized satellites result in most of the pictures being obtained with oblique views and, too frequently, the cameras or photocells are not directed at the Earth's surface at all. This complication can be avoided by using Earth-oriented satellites. Moreover, the Tiros and Vanguard satellites are not in polar orbits and, therefore, the Earth cannot be viewed in its entirety. Consequently, it is necessary to go to polar orbits in order to view the whole Earth at least once each day. In order to obtain this view from one satellite, it is also necessary to develop a system for obtaining cloud information at night. This may be done by using infrared sensitive detectors or camera systems sensitive enough to view clouds under moonlight or starlight conditions.

Infrared radiation sensors are planned for the second Tiros satellite. One of these sensors may give information on nighttime cloud distribution. The resolution, however, will be very low and at most will yield information on only the very large-scale distribution of clouds. It is necessary, therefore, to develop techniques which will give much higher resolution cloud pictures at night. Sometime in the future, it may be possible to use radar operating on a wavelength of one centimeter or less to detect clouds both day and night. While the resolution which can be expected with radar will never be as good

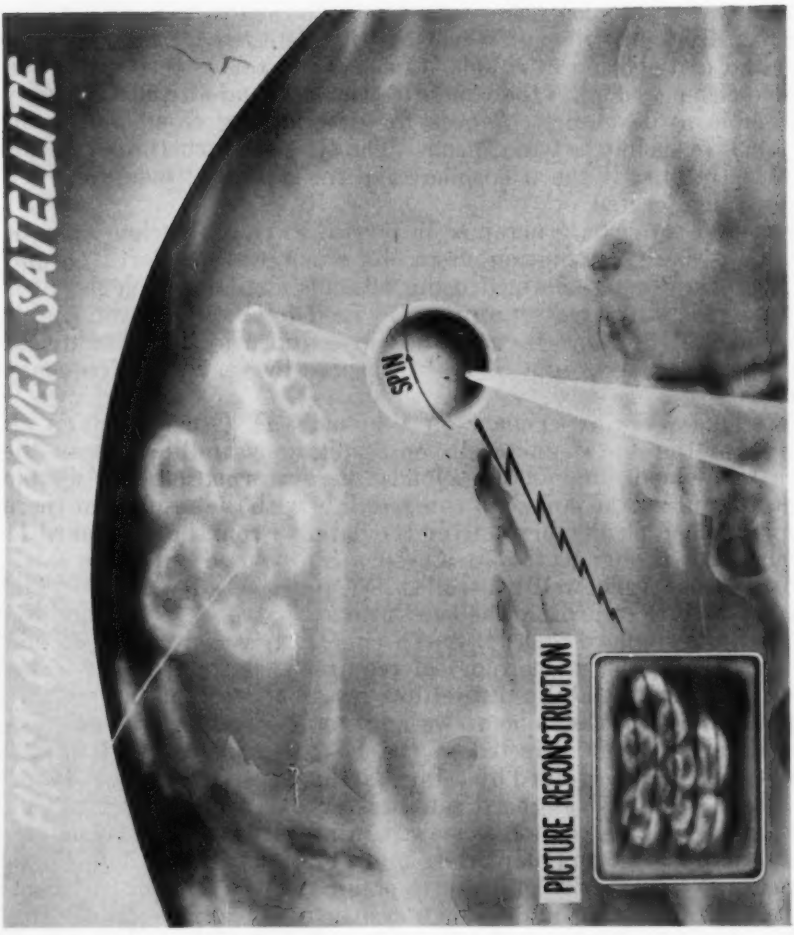


FIGURE 32

as that attainable with other systems, it will have the advantage in giving us some information on the vertical distribution of cloud layers in addition to precipitation. Another possibility lies in the ruggedization of image orthicon TV systems for satellite application. These systems are able to operate on reflected moonlight and possibly even starlight.

RADIATION MEASUREMENTS

Satellite radiation measurements are of particular interest because they represent an exchange of energy between the Earth and space. Moreover, the radiation spectrum (specifically between 0.2–35μ) emitted by the Sun and Earth contains significant frequency bands corresponding to particular solar, atmospheric, and terrestrial physical phenomena. It is thus important (1) to acquire a better knowledge of the full radiation spectrum in order to calculate the energy exchange between Earth and space and (2) to measure the energy emitted in characteristic frequency bands in order to infer the magnitude of the atmospheric physical parameters to which they are correlated. As an example of the latter, it is possible to deduce certain temperatures from specific spectral radiation measurements (by making suitable assumptions concerning radiating bodies).

Explorer VII (shown in fig. 33), launched on October 13, 1959, is still providing useful data of heat budget measurements. It uses a nonscanning IR radiation detector system. Radiation data results for the flight of Explorer VII on December 3 are given in figure 34.

COROLLARY MEASUREMENTS

Paralleling the development of instruments to be flown on satellites, measurements with these instruments must be made from the ground and from balloons (and aircraft, if feasible) in order to test the apparatus and check the theoretical work which relates the measurements at optimum wavelengths to the desired temperatures and atmospheric components.

OTHER MEASUREMENTS

Mook and Johnson ("A Proposed Weather Radar and Beacon System for Use With Meteorological Earth Satellite," third National Convention on Military Electronics, IRE, Washington, D.C.) have made a preliminary survey of the problem of radar onboard a satellite. They state:

> In the early days of microwave radar, a nuisance developed which was later to become one of the most valuable tools in the kit of the meteorologist. This was the observation that cloud and precipitation particles would act as scatterers or reflectors of microwave radiation and had to be reckoned with in the design and use of radar. As the secrecy veil gradually lifted on radar and as more and more meteorologists were given access to the new instrument, developments took place at a rapid pace. Radar has become not only an important tool in the probing of clouds in studies of the physics of the atmosphere, but an important tool in the detection, tracking, and forecasting of hurricanes, tornadoes and other storms. In addition to the characteristic patterns of these storms, the bright band seen in echoes from precipitation falling through the freezing level has become not only a method for detecting the height of the melting layer but an important adjunct to the short-term forecasting of snowstorms.

EXPLORER VII

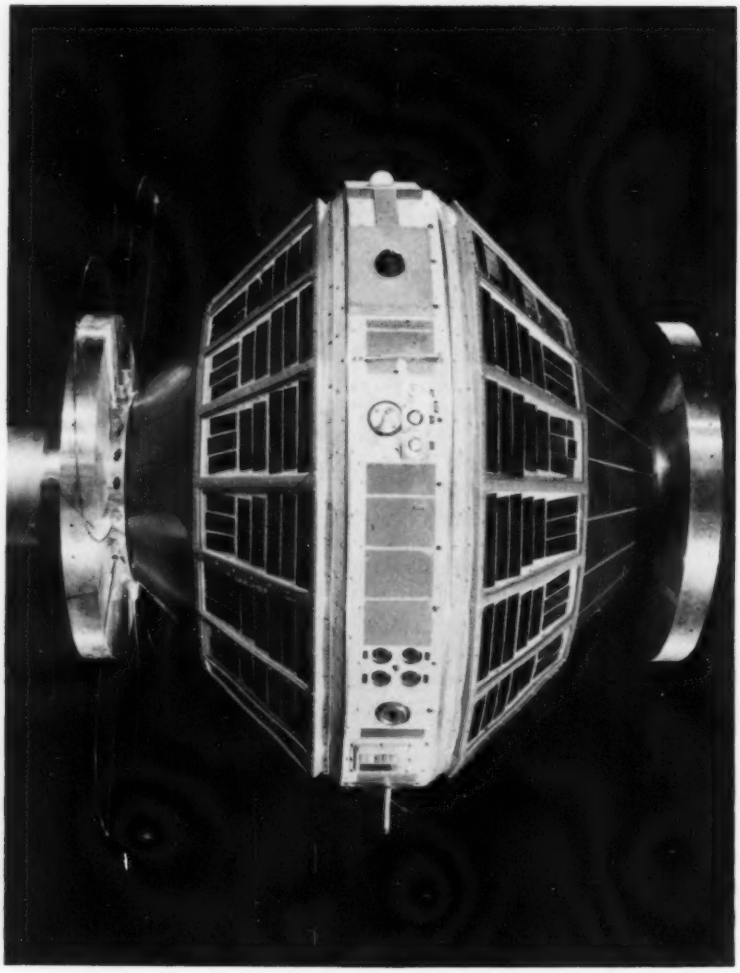


FIGURE 33

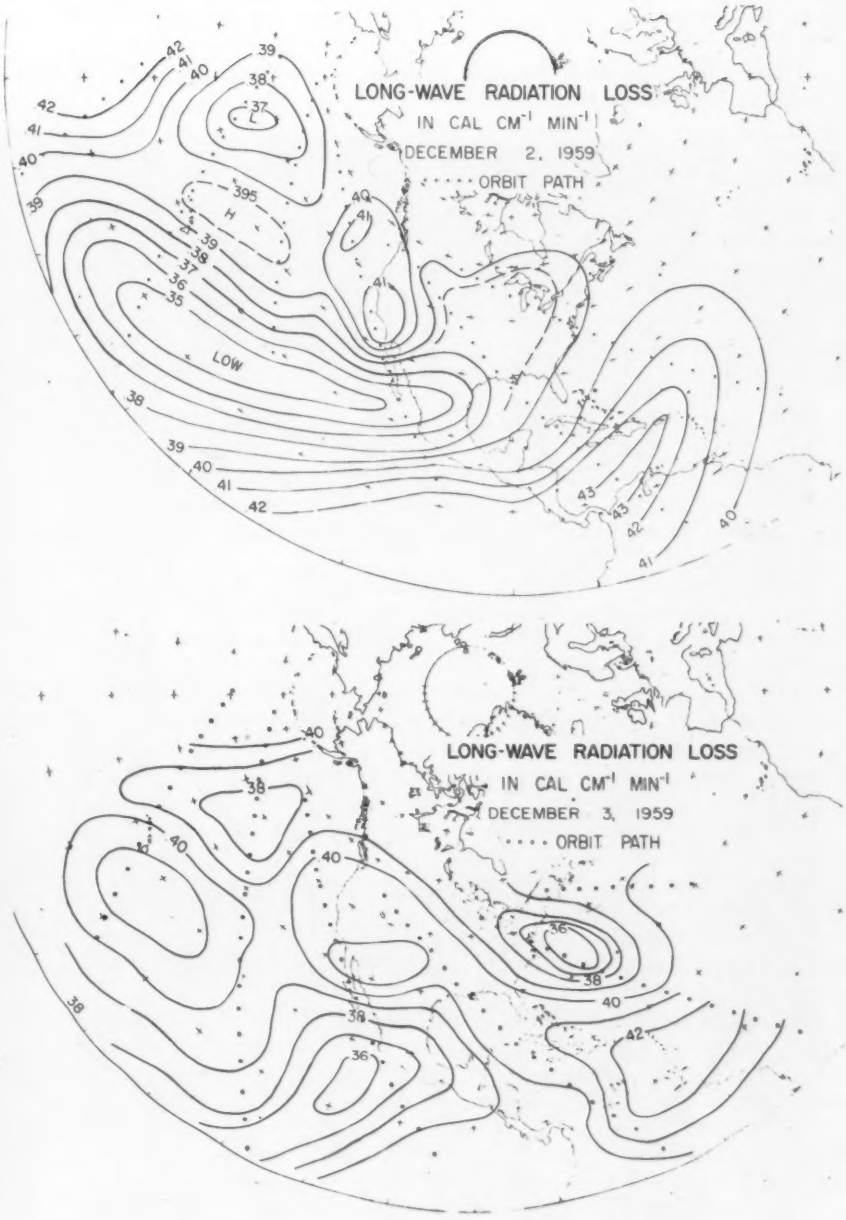


FIGURE 34.—Long-wave radiation loss.

Just as it is important to have as wide a coverage as possible at the ground by surface radar sets, it becomes even more important to survey the possible use of radar as a means of continuous storm surveillance over the entire Earth from one or more satellites * * *."

Although it shall be possible to take cloud cover pictures by television and photocell techniques—

there are limitations inherent in both methods including the fact that the presence of rain in the clouds is not now detected and there are limitations on the usefulness of these methods over the dark side of the Earth.

In view of the increasing payload capabilities of the boosters of the near future, it is not anticipated that the weight and size of the radar will present any serious problem. However, suitable antennas, reliability of the system and power available are important considerations.

Observations of variable solar ultraviolet and X-ray radiation, energetic particle and meteoric dust from space should also be included in the satellite program for correlation with unusual weather behavior.

THE FLIGHT PROGRAM—TIROS I

Tiros I is the satellite which was placed in orbit April 1, 1960, from the Atlantic Missile Range. The term Tiros, is derived from television and infrared observation satellite. Figure 35 shows a cutaway view of Tiros I.

Tiros I weighs 270 pounds and is following a very precise circular orbit, approximately 450 miles above the Earth. Primary satellite instrumentation consists of two TV cameras to take still photographs of the Earth's cloud cover.

The satellite looks like a giant pillbox, 42 inches in diameter and 19 inches high. Its appearance is somewhat unusual since its top and sides are almost completely covered by banks of solar cells—about 9,200 in all. Extending beneath the payload are four transmitting antennas. A single receiving antenna is located on the top.

Orbital inclination is about 50 degrees to the Equator. Traveling about 18,000 miles per hour, the satellite circles the Earth every 99 minutes. The belt covered by the orbiting Tiros extends from 50° N. latitude to 50° S. latitude. In the Western Hemisphere this covers an area between Montreal, Canada, and Santa Cruz, Argentina. During its approximately 1,300 orbits over a 3-month period, Tiros will sweep over every point in this belt.

This satellite, in addition to its TV cameras and associated equipment, contains beacon transmitters, attitude sensors, and telemetry circuits. Power is supplied by nickel-cadmium batteries charged by solar cells. Power output averages about 19 watts.

There are two primary ground stations which both command the satellite and receive photo data. These are located at Fort Monomouth, N.J., and Kaena Point, Hawaii.

The two Tiros TV cameras differ in coverage and resolution. The wide-angle camera is designed to cover an area of cloud cover roughly 800 miles on a side. The narrow-angle camera will photograph a smaller area located within the wide-angle camera's view.

Identical except for lens equipment, the cameras are both the size of a water glass and use a one-half inch vidicon tube especially designed for satellite use. Each camera consists of two parts: A vid-

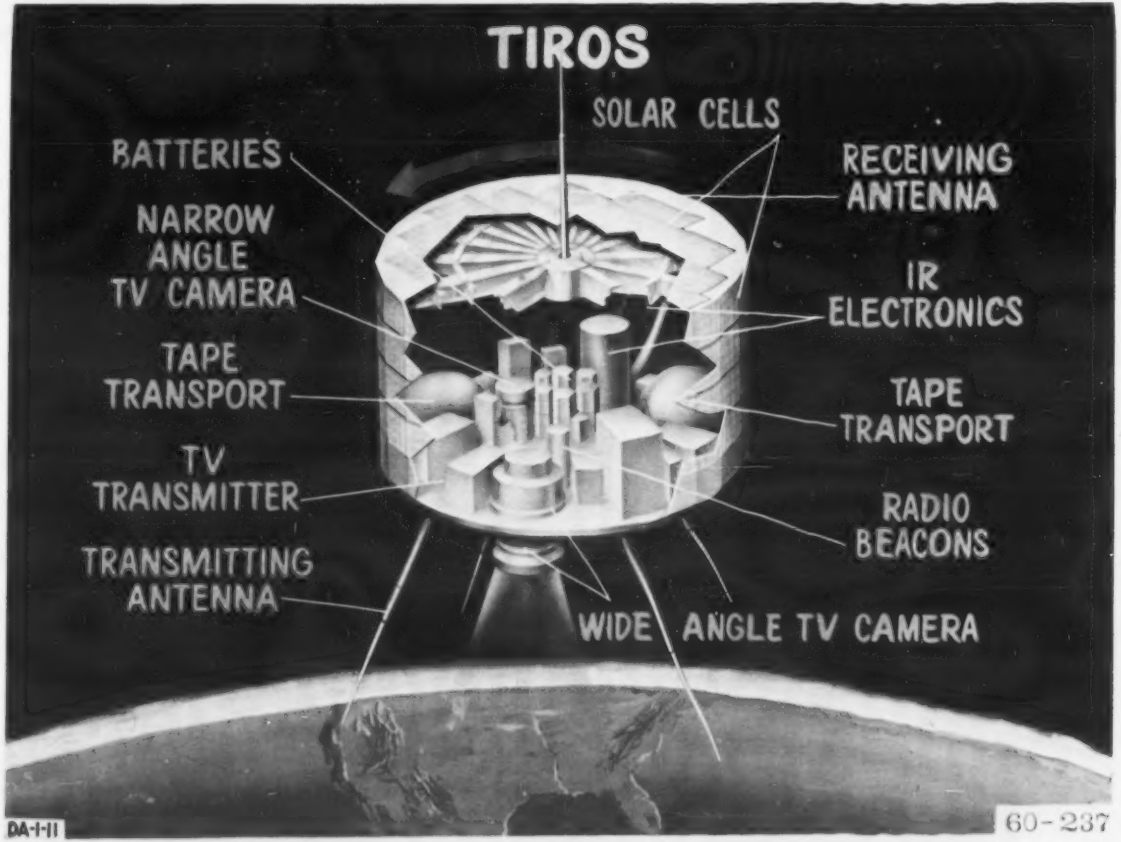

TIROS
SOLAR CELLS
BATTERIES
RECEIVING ANTENNA
NARROW ANGLE TV CAMERA
IR ELECTRONICS
TAPE TRANSPORT
TAPE TRANSPORT
TV TRANSMITTER
RADIO BEACONS
TRANSMITTING ANTENNA
WIDE ANGLE TV CAMERA
DA-1-11
60-237

FIGURE 35

icon and a focal plane shutter which permits still pictures to be stored on the tube screen. An electron beam converts this stored picture into a TV-type electronic signal which can be transmitted to ground receivers.

These are some of the characteristics of the cameras: Lens speed—wide-angle, f/1.5; narrow-angle, f/1.8; shutter speed, 1.5 milliseconds; lines per frame, 500; frames per second, one-half; video bandwidth, 62.5 kilocycles.

Connected to each camera is a magnetic tape recorder. Out of ground station range, Tiros can record up to 32 photographs on each storage tape for later delay. Or, picture data from the cameras can bypass the tape and be transmitted directly to the ground when within range of a station. The Mylar-base tape is 400 feet long and moves 50 inches per second during recording and playback. The two TV systems and their associated equipment operate independently of one another.

Photo data are transmitted from one camera at a time. Tape readout from both cameras takes about 3½ minutes. The satellite is within transmission range of ground stations up to 12 minutes. This means that the satellite can transmit directly up to about 4 minutes of photo data collected while within range of the acquisition station. Connected to each photo system is a 2-watt FM transmitter operating at a nominal frequency of 235 megacycles which relays picture information on command to ground stations.

At the ground stations, pictures are displayed on kinescopes for immediate viewing and photographing. Photo data is also sent to the U.S. Naval Photographic Interpretation Center for developing and processing.

Two beacon transmitters, operating on 108 megacycles and 108.03 megacycles, both with a power output of 30 megawatts, are used for tracking purposes. They can be modulated to provide information on satellite attitude, environmental conditions, and satellite equipment operation. For backup purposes, both frequencies carry the same data. Each of the photo data acquisition stations are equipped with tracking antennas.

When the payload was separated from the third stage of the Thor-Able launching vehicle it was spinning at about 90 revolutions per minute. Pictures taken from a vehicle with this rate of spin would be blurred. About 10 minutes after payload separation a despin mechanism slowed the revolutions to within camera operating limits—10 revolutions per minute. The despin mechanism consisted of two weights attached to cables wound around the satellite. The weights unwound, slowed the rate of spin, and then dropped off automatically.

The satellite is expected to remain stable in its orbit as long as it maintains a minimum spin rate of 9 revolutions per minute. When the spin slows to about the minimum, control rockets will speed the satellite's rotation back to about 12 revolutions per minute. There are three pairs of these jets located around the base plate of Tiros. Each set can be used once. These jets are activated by command from the ground.

An infrared detector within the payload senses the crossing of the Earth's horizon. This is transmitted to ground stations for process-

ing to determine the attitude in space of the satellite's spin axis; it also can be used as a basis for computing spin rate.

Since Tiros is spin-stabilized, it is not "looking" at the Earth at all times. Based on tracking information, Fort Monmouth and Kaena Point program the cameras to take photographs only at those times when the satellite is viewing the Earth and when the area to be photographed is in sunlight. This is done by setting a timer. Program commands can be given as much as 5 hours in advance. Pictures taken while Tiros is out of range of the ground stations are stored on tape for later relay. In the remote mode, the timer starts the camera, power, and transmitter functions. Each read-out wipes the tape clean. It immediately rewinds for its next recording.

When the satellite is within range of a station, ground command can directly turn on the cameras, and photographs taken above the station are relayed immediately below, bypassing the magnetic tape.

Some of the photographs which have been received from Tiros I are shown in the accompanying figures.

Figure 36 shows a series of photographs taken during the second orbit of Tiros I on April 1, 1960, at about 10:15 a.m. e.s.t. from a point several hundred miles east of the Atlantic coast and from an altitude of aproximately 450 statute miles. The white area shows the cloud mass that rises over the Northeastern United States and Canada. The dark area at the bottom right is the Gulf of St. Lawrence.

Figure 37 shows the definition of the western coast of French West Africa. The area extends from approximately Cape Blanco to St. Louis, French West Africa. The picture was received on the 31st orbit of Tiros I on April 4, 1960.

Figure 38 shows a typhoon in the South Pacific about 1,000 miles east of Brisbane, Australia, and was taken during the 125th orbit of Tiros I on April 9, 1960. The typhoon is indicated by the spirallike clouds winding around the center of the "eye" of the storm.

Figure 39 is a photograph taken by Tiros I over north Africa looking downward and to the west showing the Strait of Gibraltar in the center of the picture. Spain is shown on the right of the picture, Portugal is covered by cloud formation. The coast of Morocco and the western part of the Mediterranean coast of Algeria appear on the left side of the picture. The dark area in the forground is the Mediterreanean Sea, and in the background is the Atlantic Ocean.

Figure 40 illustrates the contrast between photographs taken with the wide-angle camera and the narrow-angle camera contained in Tiros I. On the left photograph is shown cyclonic flow indicated by giant bands of clouds covering thousands of miles in width over the central Pacific. On the right is the narrow-angle camera detail of the cloud structure shown in the center of the photograph on the left.

Figure 41 shows the cloud system associated with a cold front system over Central United States. The weather map which is for the same time shows the remarkable correspondence in appearance between the cloud pattern and the weather system.

Participation in Tiros has been extensive. Tiros was initially begun in the DOD. On April 13, 1959, overall project direction and

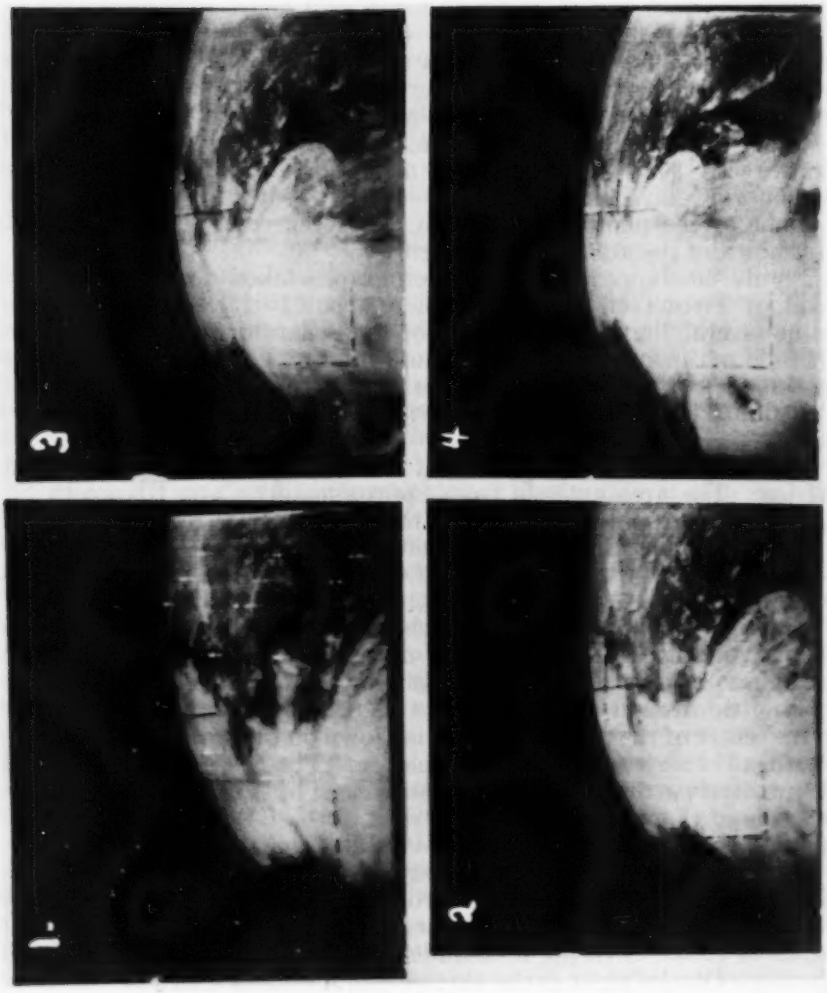


FIGURE 36.—Photographs taken from Tiros I (see text, p. 657, for description).

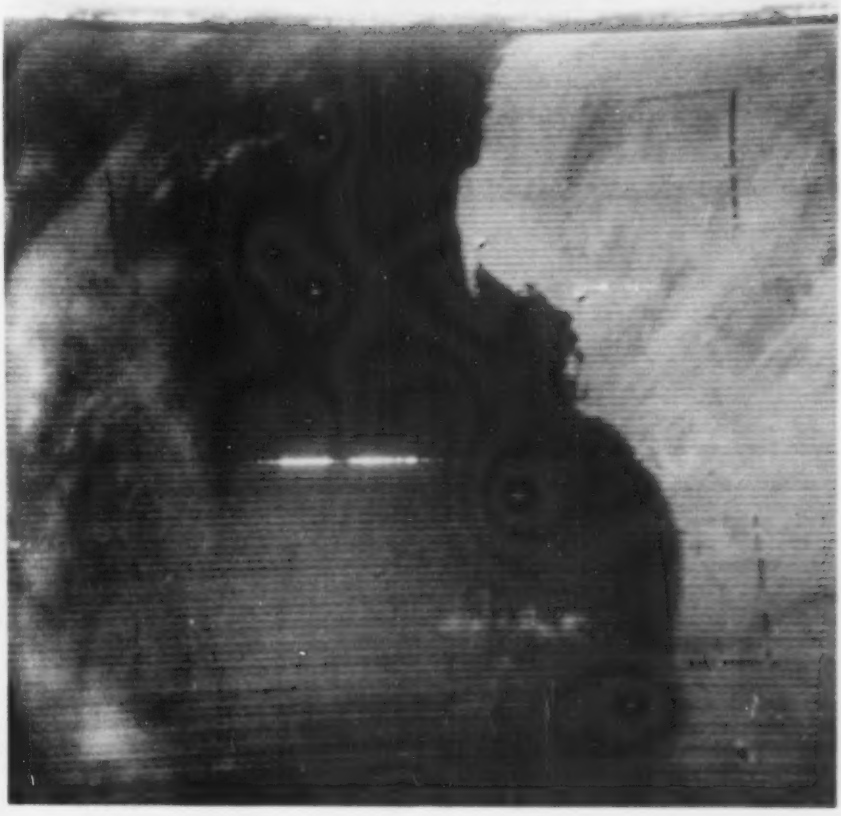


FIGURE 37.—Photograph taken from Tiros I (see text, p. 657, for description).

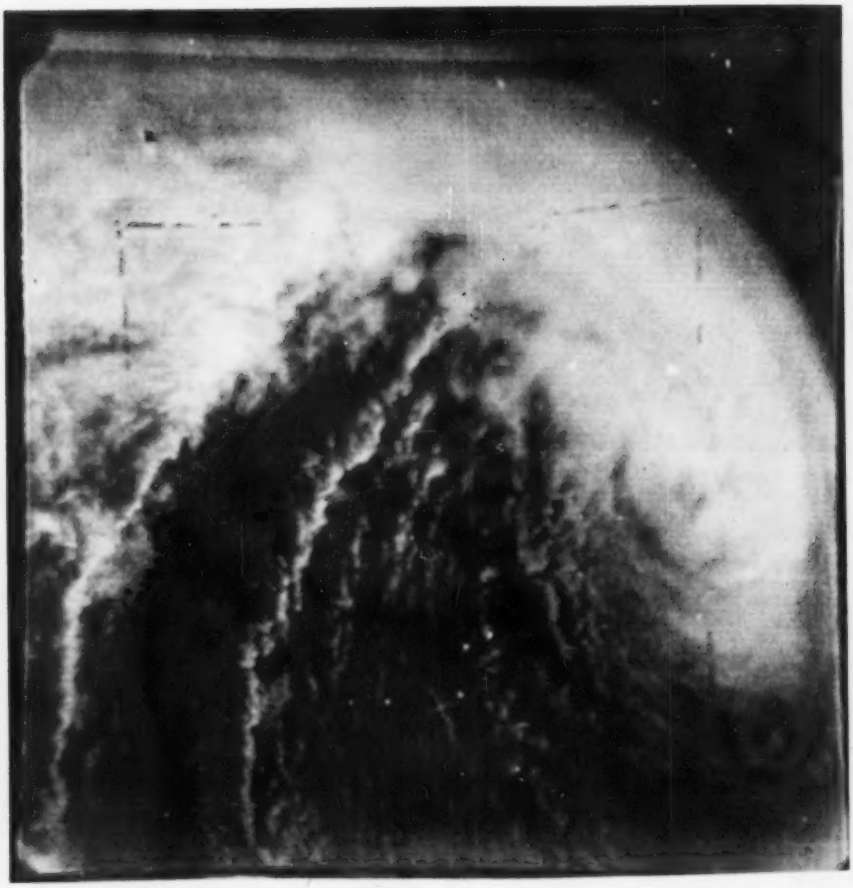


FIGURE 38.—Photograph taken from Tiros I (see text, p. 657, for description).

FIGURE 39.—Photograph taken from Tiros I (see text, p. 657, for description).

53795 O—60—pt. 2——7

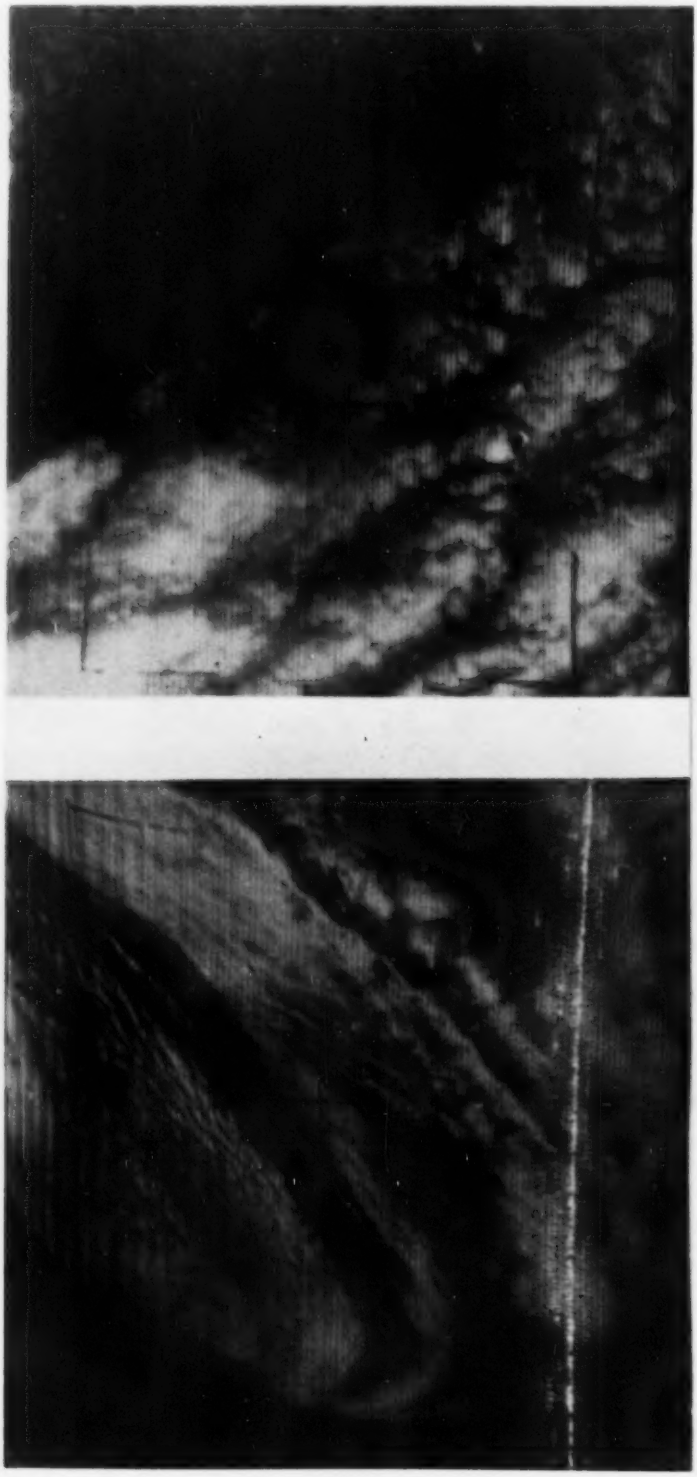


FIGURE 40.—Photographs taken from Tiros I (see text, p. 657, for description).

FIGURE 41.—Cloud system associated with a cold front (see text, p. 657, for description).

coordination was transferred to NASA. The basic responsibilities for Tiros I are:

U.S. Army (USASRDL and contractors from industry—primarily RCA): Development of payload and selected ground equipment, data acquisition and data transmission.

U.S. Air Force (BMD and contractors from industry—STL, Douglas, and Lockheed): Development of launch vehicle, mating of vehicle and payload, launch, data acquisition. AFCRC assists with data analysis and interpretation.

U.S. Navy (NPIC): Assists in the photoanalysis.

U.S. Weather Bureau: Data analysis and interpretation, data dissemination and historical storage.

The Tiros satellite is but an experiment—in itself it cannot be considered an operational weather system. Its useful lifetime is expected to be only about 3 months. However, if a meteorological satellite relaying weather data to Earth proves feasible, such a system consisting of several satellites providing coverage over the entire globe may one day be used on a continuing 24-hour basis.

During the 12-month period following the launch of Tiros I, there will be two additional launches of satellites in the Tiros family. The basic instrumentation in all these flights will be a vidicon television system by means of which cloud cover information will be viewed and transmitted back to a read-out station. In the second and third flights, infrared radiation sensors will also be included.

Following the termination of the Tiros series, there will begin the program in the Nimbus series of meteorological satellites. This will be a family of satellites with many common components (data storage, controls, orientation, stabilization, data transmission, structure, etc.) and a flexible capability for improving old and introducing new sensory systems, as required.

Launchings will be about twice a year in a 600-mile polar orbit using a Thor-Agena B vehicle. Nimbus I is planned to be launched late in calendar year 1961 with each succeeding satellite following about 6 months later.

Figure 42 shows the two basic differences in the orbital properties of the satellites in the Tiros family and those in the Nimbus family.

NIMBUS

The Nimbus satellite will be separated from the Agena stage upon injection into orbit. Its weight will be 650 pounds and its life expectancy 6 months. It will consist of three subsystems—power, stabilization, sensory.

In figure 43 we see a mockup model of Nimbus and its three major subsystems.

The power subsystem will consist of two paddlelike structures covered with solar cells and arranged to face the Sun directly, whenever the satellite is in the sunlight. Nickel-cadmium storage batteries will be used for power storage. The average power input of the power subsystem will be designed for 200 watts per orbit.

The stabilization subsystem located in the upper portion of the satellite will keep the satellite pointing directly at the Earth with an accuracy of 1° in all three axes—roll, pitch, and yaw. The perturba-

METEOROLOGICAL SATELLITE DEVELOPMENT
TIROS
NIMBUS
INCLINED ORBIT
SPACE ORIENTED
POLAR ORBIT
EARTH ORIENTED

FIGURE 42.

NIMBUS

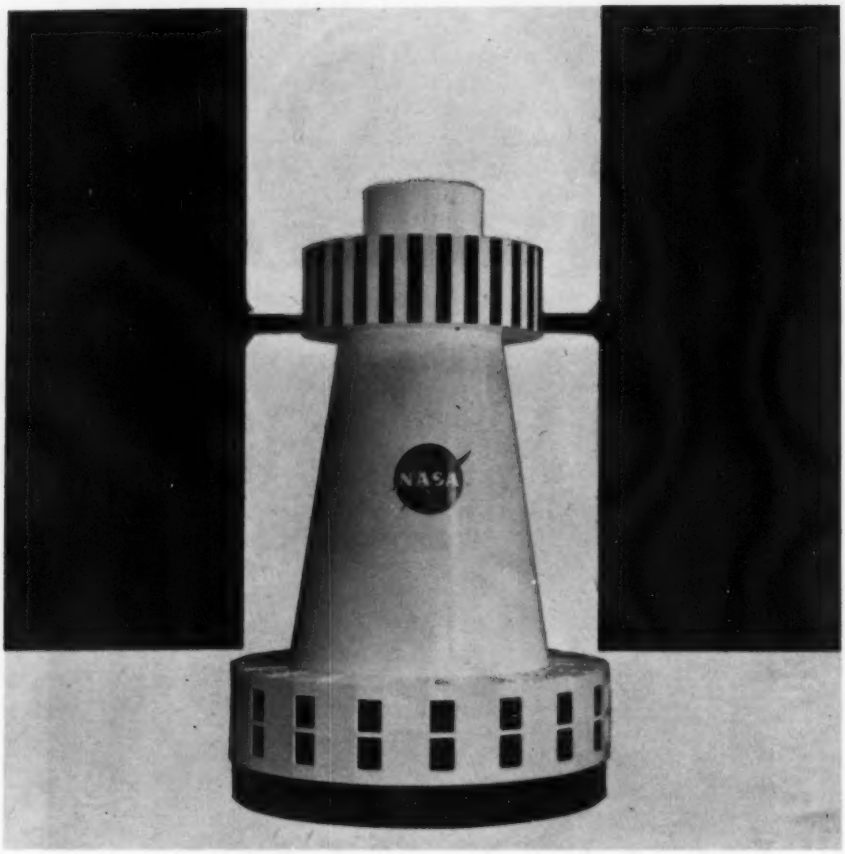


FIGURE 43.—Mockup model of nimbus.

tion rate will not exceed 0.1° per second in any of the axes. Pneumatic jets will provide the coarse control and inertia wheels, the fine control.

The sensory subsystem located in the lower portion of the satellite will consist of (1) an improved TV vidicon subsystem to provide almost complete coverage of the globe, (2) an electrostatic tape subsystem to permit higher resolution studies of specific meterological events, such as hurricanes, (3) a comprehensive infrared radiation subsystem containing (*a*) high resolution (5-mile) sensors for coarse nighttime cloud cover representation, (*b*) medium resolution (30-mile) sensors for atmospheric and terrestrial radiation measurements, and (*c*) low resolution (300-mile) sensors for gross measurements of the Earth-atmosphere heat balance, and (4) auxiliary measurements of importance to meteorology: Measurements of the solar constant, solar ultraviolet radiation, and solar particle radiation.

The launch vehicle for the Nimbus series will be the Thor-Agena B. It is a two-stage vehicle in which the first stage consists of a production Thor with the nose cone and guidance unit removed. The first-stage propellants are liquid oxygen and RP–1 (kerosenelike) fuel. The second stage consists of an Agena B vehicle. The Agena B is an improved version of what was previously designated as the Hustler stage.

In the Nimbus I launch, the Thor-Agena B will lift a 650-pound payload to an altitude of 600 miles. The orbit will be circular and inclined approximately 80°, slightly retrograde, so that the plane of the orbit always includes the Earth-Sun line. By proper choice of launch time, the satellite will always pass over chosen areas at local noon.

DEVELOPMENT OF ADVANCED INSTRUMENTATION

NASA is maintaining an active instrument development program to improve the performance and reliability of existing flight instruments and to develop new instrumentation to provide additional meteorological data not yet available. Existing electronic components and systems will be improved, and development will continue on infrared radiation scanning detectors and direct radiation sensors.

Among the new kinds of instrumentation, development will proceed with satellite radar for measuring precipitation, image orthicon TV systems for day and night cloud cover picture taking, and a satellite spectrometer for the fine resolution measurements of certain radiation intervals. The evaluation and testing of new horizon detectors, gyro controls, torque controls and reaction jets to afford stabilization and control for the new generation of satellites will be pursued aggressively.

Improvements in future satellites of the Nimbus series will be sought through the continuance of an aggressive program in the development of advanced instrumentation. As the improvements are perfected they will be made part of the flight program.

BASIC RESEARCH IN SATELLITE UTILIZATION

Concurrent with the flight development program and the acquisition of meterological information, NASA supports research in the more

fundamental aspects of the overall problem of utilizing satellites for meteorological purposes. This includes:

(1) The study of actual satellite data and of satellite-simulated data from other sources, e.g., rocket probes, aircraft reconnaissance, and standard meteorological observation sources.

(2) Studies of basic atmospheric physics related to possible satellite instrumentation.

(3) Basic radiation studies including the interpretation of balloon-flown radiation sensors.

(4) Investigation of systems for simplifying the presentation of data.

(5) Studies for reducing the amount of information transmitted by the satellite by providing onboard analysis.

COMMUNICATIONS

By Leonard Jaffe, Chief, Communications Satellite Program, NASA

THE NEED

Many studies have been made which indicate the need for a much more advanced global communications capability. The need for rapid and reliable military communications is quite obvious. The future requirements of communications for commercial and scientific purposes will be significantly greater.

In 1950 approximately 1½ million oversea telephone calls were made. The current rate is at least 3 million oversea calls per year and this number is expected to increase to approximately 21 calls per year in another decade. This predicted demand is based largely on present economic conditions remaining the same and that no new vast areas of commercial interest will develop. Certainly the future will require that communications be supplied with areas of the world not being served today and these communications will not be limited to telephone calls, but it will include truly global television transmission and the transmission of vast quantities of scientific and commercial data. It might be well to amplify this last point. The advent of the electronic computer has brought about a revolution in our ability to analyze tremendous quantities of information and we must have the means with which to transmit data from the sources to the computer. As a matter of fact, satellites have become large producers of data. Tiros, the weather satellite, has already produced many thousands of pictures which must be analyzed. If this type of information is to be of value in weather forecasting it must be transmitted and analyzed immediately, for by its very nature its value is perishable.

The only reliable oversea communications systems in existence today are the submarine cables. There are only two telephone cables across the Atlantic Ocean with the capability of carrying approximately 100 simultaneous telephone calls. There exists no method for transmitting television across the large oceans for television transmission requires roughly 1,000 times the capability of a telephone circuit. High frequency radio circuits are not reliable because of their susceptibility to varying ionospheric conditions. The use of satellites to provide global

communications represents the most promising solution to this problem.

There are a number of ways in which satellites can be used to provide communications, but one can separate the many methods into two broad categories; active satellites which contain electronics necessary to rebroadcast a message, and passive satellites which contain no electronics but merely act as reflectors of radio signals. These two philosophies differ markedly in the amounts and complexity of the equipment carried aboard the satellite in each case.

PASSIVE COMMUNICATION SATELLITES

One of these systems is called the passive communications satellite. This refers to a satellite in which there are no electronics. This system is shown in figure 44. With this type of satellite, communication is established by merely reflecting radio waves which impinge upon the satellite back toward the Earth. All of the power which is necessary to accomplish communications between two stations must originate on the Earth, since there is no power available in the satellite itself.

Therefore, we require large or high powered transmitters at the ground sending station. We require large antennas to beam the energy toward the satellite. Since this reflected energy from the satellite is spread out in all directions, the receiver must necessarily be a very sensitive receiver requiring very low noise amplifiers or very highly sensitive amplifiers. Further, since the satellite is moving in its orbit, we need large steerable directional antennas to concentrate as much energy at the satellite and to absorb or pick up as much of the reflected energy as possible.

In addition to this it would require computing equipment to calculate the trajectories and provide this antenna pointing information as the satellite progressed in its path.

The series of experiments which NASA will conduct in the passive communications satellite field has been named Project Echo and is designed to develop the technology necessary to the establishment of durable structures in space and the evaluation of their use as communications satellites.

One of the Echo satellites will be a 100-foot diameter inflatable sphere developed by the NASA Langley Research Center. It is constructed of the plastic mylar, one-half-thousandth of an inch thick, with a vapor-deposited coating of aulminum to provide reflectivity. The sphere weighs approximately 136 pounds and has 31,416 square feet of surface area. The satellite is folded into a container 26 inches in diameter and the container is evacuated to a low pressure. A subliming material (one that passes directly from a solid to a gaseous state) is placed into the sphere before packaging to provide for inflation of the sphere in the vacuum of space after it has been released from its container. When established in orbit, the sphere will be used to demonstrate the feasibility of using such spherical satellites for communications, and to perform communications experiments described below.

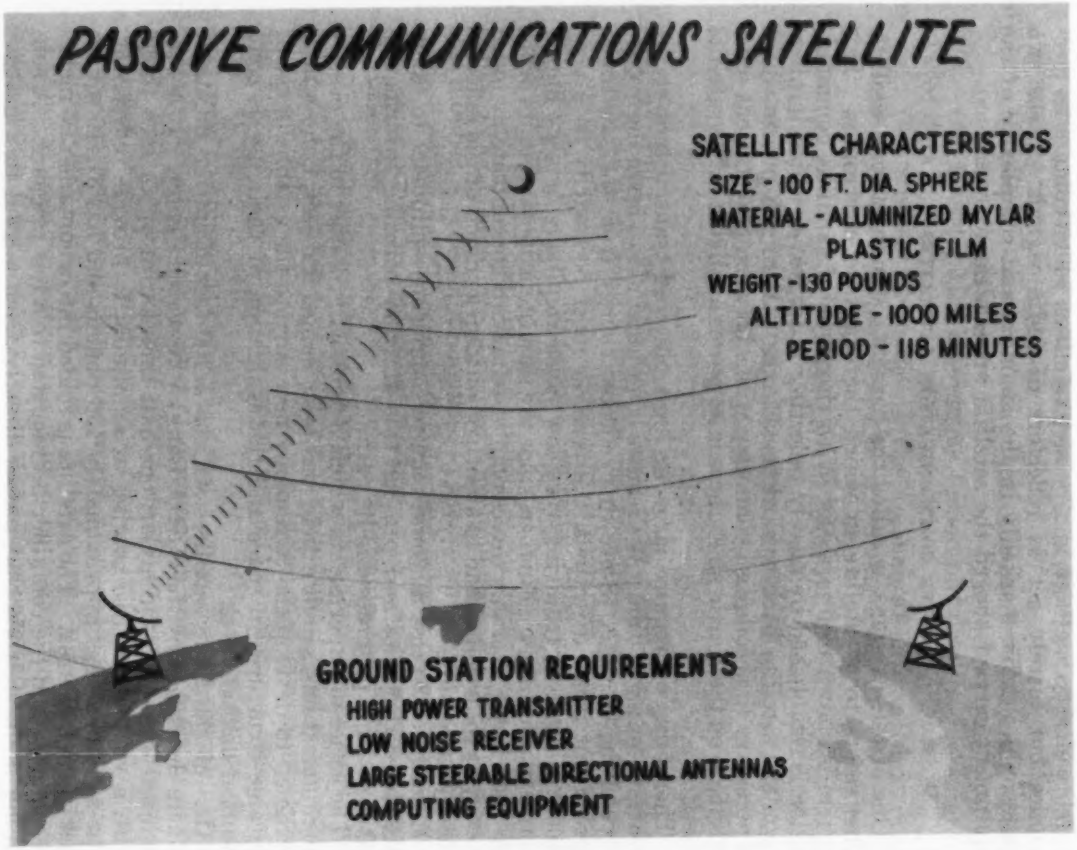

PASSIVE COMMUNICATIONS SATELLITE
SATELLITE CHARACTERISTICS
SIZE - 100 FT. DIA. SPHERE
MATERIAL - ALUMINIZED MYLAR PLASTIC FILM
WEIGHT - 130 POUNDS
ALTITUDE - 1000 MILES
PERIOD - 118 MINUTES
GROUND STATION REQUIREMENTS
HIGH POWER TRANSMITTER
LOW NOISE RECEIVER
LARGE STEERABLE DIRECTIONAL ANTENNAS
COMPUTING EQUIPMENT

FIGURE 44

COMMUNICATIONS EXPERIMENT

To evaluate the communications capabilities of satellites established during the flight program, NASA has instituted a program and is providing facilities to be used in communications research (figure 45). Two primary facilities are under development: the JPL Goldstone facility on the west coast and the Bell Telephone Laboratories facility (development costs borne by Bell Laboratories) at Holmdel, N.J., on the east coast. Special transmitters, receivers, antennas, and antenna-pointing equipment have been developed for these communications terminals. These stations will demonstrate the feasibility of satellite communications and in addition investigate radiofrequency transmission characteristics, modulation techniques and tracking techniques as well as determine the shape of the satellite in orbit. The Naval Research Laboratory will also participate in this program.

These facilities, as well as the Lincoln Laboratory Millstone radar, which will track the satellite, will be used throughout the research and development phases of the NASA communications satellite program. Additional developments for these sites will be required to keep pace with the satellite developments.

The BTL and JPL communications systems have been completed and have been exercised in preparation for the orbital Project Echo experiment by using the Moon and the Tiros satellite as reflectors.

We will establish communications at one frequency going from east to west, and at another frequency from west to east; doing this at two different frequencies allows us to obtain some very interesting propagation data in addition to proving the feasibility of this type of system. In addition to this more or less in-house experiment that we are performing, we will encourage private enterprise to make their own observations using this balloon. Indeed, there is nothing within the balloon to prevent anyone from reflecting radio signals from it and from obtaining their own data.

Now what does one sphere do for us? The map in figure 46 shows the area of influence of one sphere. The dark sphere would be seen essentially from any point within the dark circle, so that two stations within this area of influence could communicate with each other. Now since these spheres are moving in their orbits, it is quite obvious that as it moves this area of influence or area of reception would move along with it, and one of these antennas would then be outside the area.

As this dark satellite moves out of the range of the two particular stations that we are interested in, we could provide another to move into its place. Thus a single satellite does not give us general coverage, but a multiplicity of satellites of this type could give us general global coverage. In the present vehicles, vehicles we have available to us today, we have the capability of launching one satellite at a time, but future vehicles might make it possible to put a multiplicity of these satellites into orbit with a single rocket.

MULTIPLE-SPHERE LAUNCH

To establish and maintain continuous communications, a number of satellites in orbit will be necessary in order that at least one is always in sight of the two stations desiring to communicate. Studies indi-

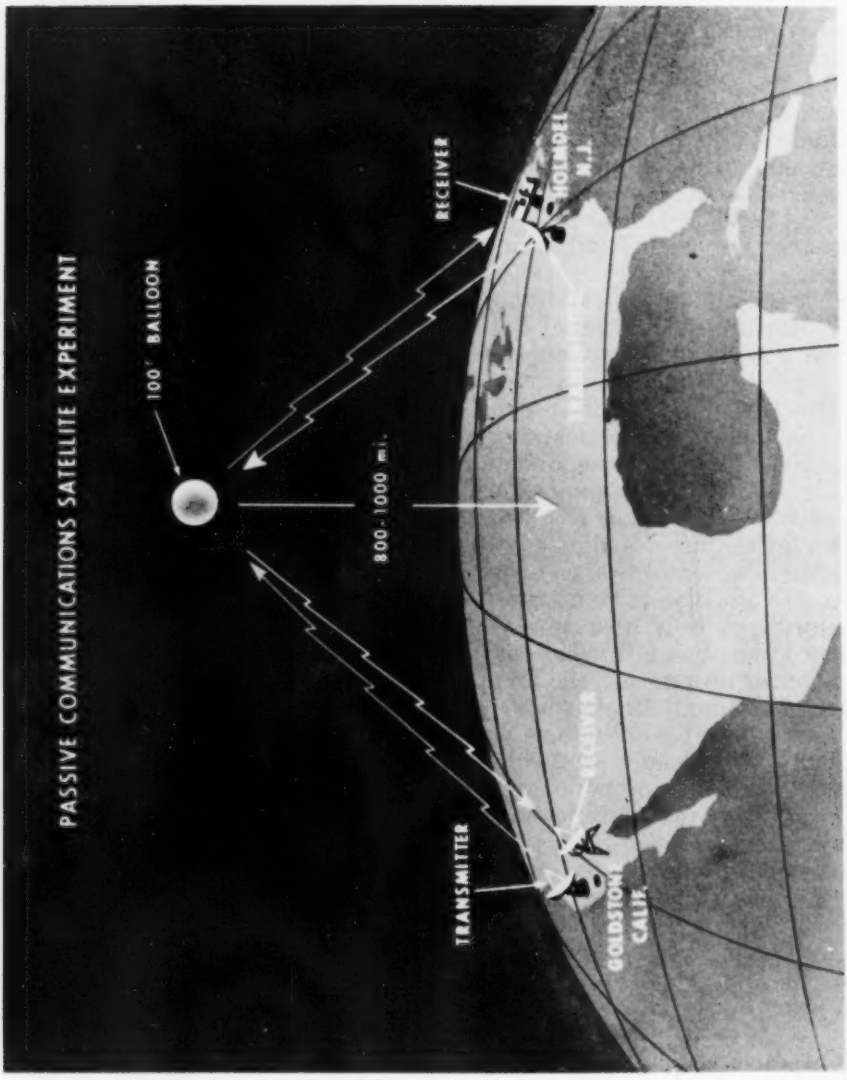

PASSIVE COMMUNICATIONS SATELLITE EXPERIMENT
100' BALLOON
800-1000 mi.
RECEIVER
HOLMDEL N.J.
TRANSMITTER
GOLDSTONE CALIF.

FIGURE 45

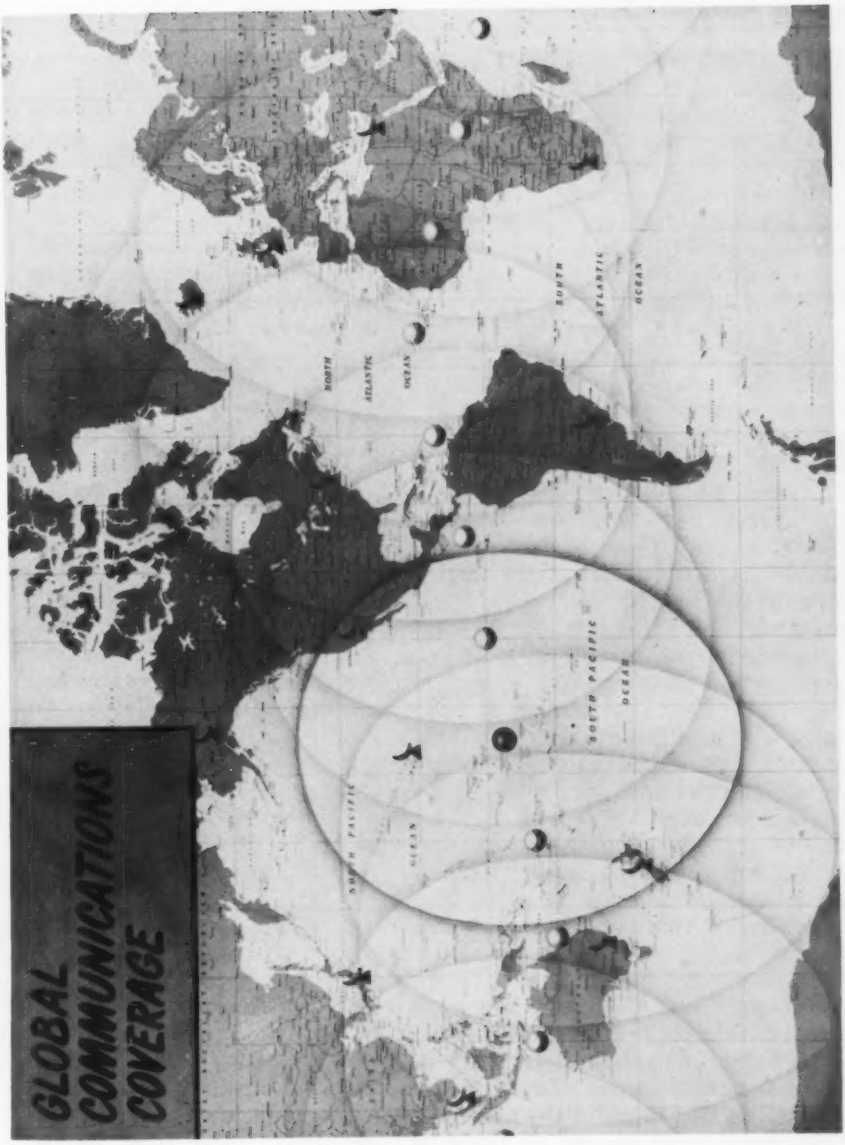

GLOBAL
COMMUNICATIONS
COVERAGE
NORTH ATLANTIC OCEAN
SOUTH ATLANTIC OCEAN
SOUTH PACIFIC OCEAN

FIGURE 46

cate if no effort is made to control the relative position of satellites, on the order of 30 spheres in a 3,000- to 4,000-mile orbit would be required to provide 99-percent availability. If it were possible to control the period of each satellite the number of spheres required could be reduced substantially.

ACTIVE REPEATER SATELLITE

The difference between the different communication satellite systems is the extent or complexity of the equipment carried within the satellite.

Figure 47 shows an active repeater satellite. As opposed to the passive repeater satellite, this satellite does contain electronics. It contains a receiver, a transmitter, an antenna, and of course the associate power supply to power this unit. A signal transmitted from the ground would be received by the satellite and immediately retransmitted on another frequency to a remote ground station. Since we have power available to us in the satellite we could use receivers of rather standard characteristics. We wouldn't have to go to the very low noise and very sensitive receivers that are required for the passive communications satellite. We could use transmitters of nominal power, because we are essentially going only half as far in each case. In the case of a low orbit satellite we would still have to follow the satellite with our steerable and directional antennas.

Another possibility is the so-called 24-hour orbit, at 22,300 miles altitude from the Earth, the satellite remains fixed with respect to a point on the Earth's surface. If we were to take three active satellites and deploy them as shown in figure 48 in this 24-hour orbit, we could get complete coverage of the Earth's surface with perhaps the exception of the polar regions. A signal could be sent from one side of the Earth to the other side of the Earth in perhaps two bounces. The signal might originate at one point, be transmitted to the satellite, come back to an intermediate point, be retransmitted to a second satellite, and finally to its destination on the other side of the Earth. An alternate technique that might be used in a satellite-to-satellite transmission, in which case the signal would go from its originating point to the first satellite, from satellite to satellite, and then to its destination.

Systems of this type probably represent an ultimate communications capability. However, it also represents a significant advance over present-day technology. It requires weights in the order of 800 to 3,000 pounds, depending on the complexity of the satellite. It requires solar cells or a reactor type of power supply, and in addition to this extremely reliable electronic equipment to give us a minimum of 2 to 3 year's useful life. It also requires the ability to stabilize the satellite and to point the antennas continuously toward the center of the Earth. These are all areas of technology which must be developed.

ADVANCED TECHNOLOGICAL DEVELOPMENT PROGRAMS

A considerable number of research, development, and study programs have been initiated to support the extensive communications satellite flight program described. These programs include economic

ACTIVE REPEATER SATELLITE
SATELLITE CONTAINS
RECEIVER
TRANSMITTER
ANTENNA
POWER SUPPLY
GROUND EQUIPMENT
RECEIVERS, STANDARD
TRANSMITTERS, NOMINAL POWER
ANTENNAS, STEERABLE
DIRECTIONAL

FIGURE 47

ACTIVE REPEATER -24 HOUR ORBIT
SATELLITE CHARACTERISTICS
WEIGHT 800 TO 3,000 LBS.
POWER SUPPLY SOLAR CELLS OR REACTOR
LIFE 2-3 YEARS
ORBIT 22,300 MILE ALTITUDE EQUATORIAL
ANTENNAS DIRECTIONAL, ATTITUDE STABILIZED

FIGURE 48

and sociological factors of communications satellites, computer techniques for data reduction, the influence of ultimate communications requirements on satellite systems, large spheres and other forms of passive satellites, rigidization techniques for space structures, propagation studies to determine radiofrequency characteristics of various structures, electrically steerable antenna arrays, scientific data transmission requirements, and stabilization systems for passive satellites. Equipment development in this area includes communications transmitter, digital antenna-pointing equipment, and radio beacons for inflatable space structures.

SPACE COMMUNICATIONS REQUIRMENTS

The problem of communications with deep space vehicles is extremely severe.

The communications system must first tell us where the space vehicle is, where it is located at the present time.

Secondly, it must send back information regarding the observed phenomenon in space. This information must be transmitted to the Earth and sent on to a data reduction center for final analysis as shown in figure 49. Thirdly, we must be able to communicate with the space vehicle in order to tell it what to do next.

Figure 50 shows the components that go into such a communications system. The sensing element measures some phenomenon in space. This information is passed through a modulator and on to a transmitter. The transmitter generates the power by which we can communicate. The energy is fed to the antenna and the antenna propagates this information back to the Earth. On the Earth, we have the receiving antenna and the receiver necessary to pick up this energy and the subsequent recording and data analyzing equipment.

Now, what determines the range over which we can communicate? First of all the transmitter, the amount of power than we can generate on the space vehicle. The more power we can generate the further the distance over which we can communicate. Secondly, the ability of the antenna to beam this energy back to the Earth. On the space vehicles that have been launched, the antennas have been what we call omnidirectional antennas, which radiate power in all directions and are thus very inefficient antennas for space vehicles. An efficient antenna is one which would concentrate this energy in the appropriate direction. The third element is, the ground receiving equipment, the ability of the ground receiver and the antenna to detect very, very small signals. The smaller the signal that we can detect, the greater the distance over which we can operate.

If we were to imagine or to take the example of an omnidirectional antenna, and the ordinary type of receiver that is currently available commercially, and calculate the amounts of power that it takes to communicate over distances in space, we get curves as shown in figure 51. The power requirement goes up rather dramatically as we go further out into space.

Secondly, as we increase the amount of information that we want to transmit per second of time, the power goes up.

To transmit a television picture through space requires roughly 5 to 10 million times the amount of power required for narrow-band

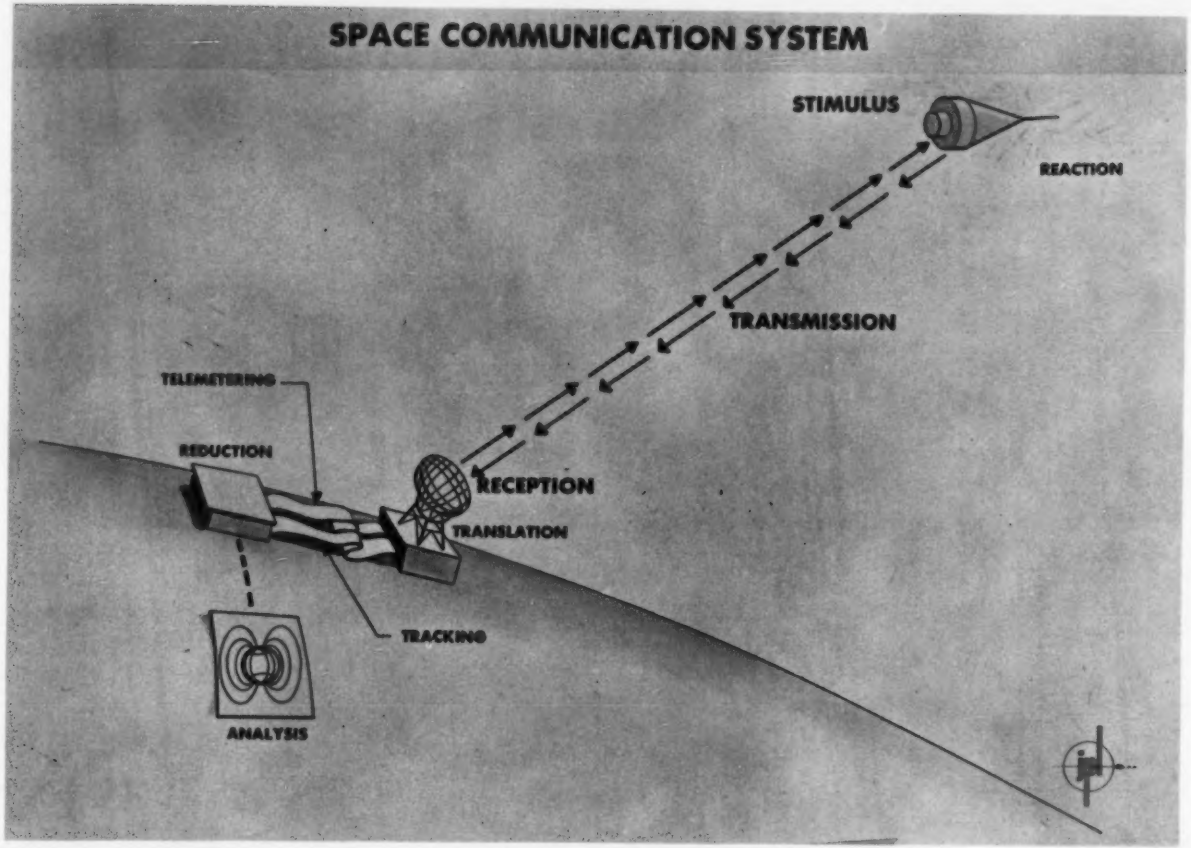

SPACE COMMUNICATION SYSTEM
STIMULUS
REACTION
TRANSMISSION
TELEMETERING
REDUCTION
RECEPTION
TRANSLATION
TRACKING
ANALYSIS

FIGURE 49

TELEMETERING SYSTEM

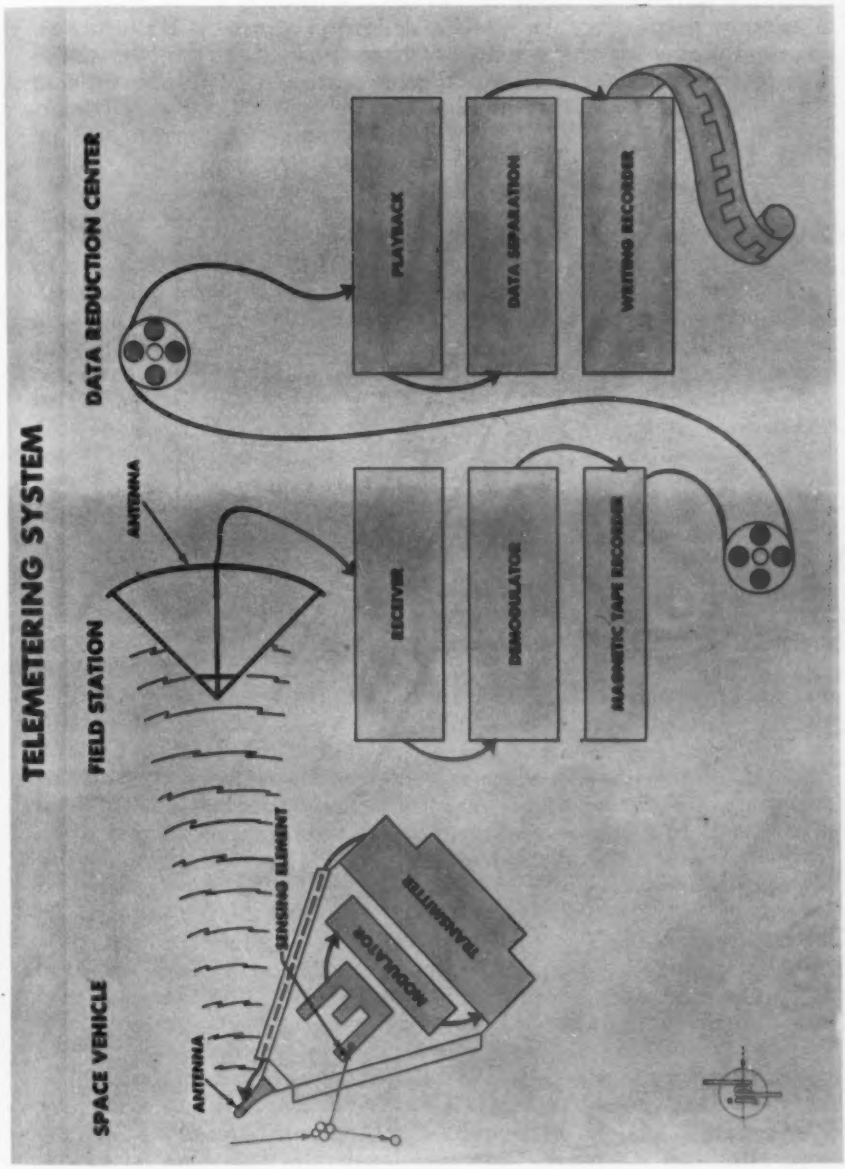

TELEMETERING SYSTEM
SPACE VEHICLE
ANTENNA
SENSING ELEMENT
MODULATOR
TRANSMITTER
FIELD STATION
ANTENNA
RECEIVER
DEMODULATOR
MAGNETIC TAPE RECORDER
DATA REDUCTION CENTER
PLAYBACK
DATA SEPARATION
WRITING RECORDER

FIGURE 50

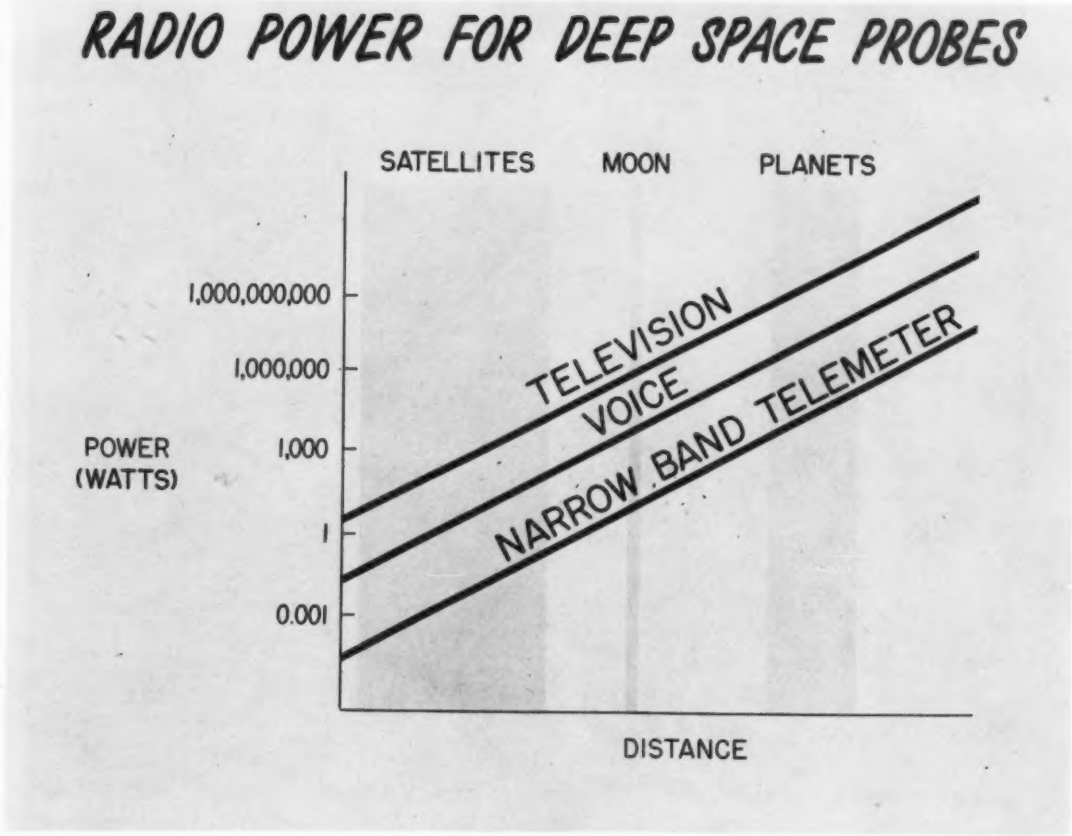

RADIO POWER FOR DEEP SPACE PROBES
SATELLITES
MOON
PLANETS
1,000,000,000
1,000,000
1,000
1
0.001
POWER
(WATTS)
TELEVISION
VOICE
NARROW BAND TELEMETER
DISTANCE

FIGURE 51

telemetry signals. To transmit voice through space requires perhaps 3 to 10,000 times the power required for telemetry signals. So, as we increase the amount of information we want to send per unit of time, the power goes up. One of the most interesting things that we can do if we are to approach planets with our space vehicles is to take a picture of the surface of the planet. If we take a look at the amount of power required to send a television picture back from a planet, such as Mars, we would end up with a figure of 10 billion watts, a formidable amount of power.

TECHNIQUES FOR REDUCING POWER REQUIRED

Now what are the techniques whereby we can reduce this amount of power? First of all, we can increase the sensitivity of our receivers, our ground receivers, and provide what are called low noise amplifiers. If we were develop a theoretically perfect low noise amplifier for the ground station, we could effect a reduction in the necessary power by a factor of 100, or this figure of 10 billion watts would be reduced to about 100 million watts. This is the theoretically perfect receiver, and we are approaching this today with the advent of so-called mazer amplifiers and the parametric amplifiers, but much work remains to be done. But this is as far as we can go with ground receivers.

What can we do next? It is possible, instead of sending a continuous television signal back to the Earth, if we were merely to take one picture of a planet's surface and store this picture on magnetic tape, we could then send it back at a very slow rate which would involve only the narrow-band telemetry rates and thus conserve tremendous amounts of power.

In figure 52 there are pictured a few of the contemplated systems for accomplishing this sort of thing. We have an optical system and a radiation detector, perhaps a photocell, which looks at a very small point on the planet's surface, and we use the spin of the vehicle itself to sequentially look at various points on the Earth's surface. This sends to the Earth a very slow picture and we would have to take these number of points and plot them and reconstruct a picture of the planet's surface, a very simple but not a really satisfactory type of system.

A much more elegant system might involve a videcon camera which takes a picture of a large segment of the planet's surface. This picture information is stored on a magnetic tape recorder and this magnetic tape recorder can then be slowed up and the information played back very slowly to the Earth.

A third system might use a camera with film on a rotating drum. We would again take a picture of a very broad segment of the planet's surface. The picture would be deposited on the film. The film would be automatically developed and perhaps a facsimile scanner could look at this drum while it rotates and read off the picture very slowly and transmit this information back to the Earth. A videcon camera might be used in a system such as this. It is a recent development, and its weight has been reduced to something like 6 pounds. Miniaturization of components will greatly facilitate our ability to communicate.

TECHNIQUES FOR REDUCING PICTURE TRANSMISSION POWER
STORAGE VIDECON
TRANSMITTER
TAPE RECORDER
VIDECON CAMERA
SPIN SCANNER
RADIATION DETECTOR
TRANSMITTER
OPTICAL SYSTEM
FACSIMILE-PHOTOGRAPH
AUTOMATICALLY DEVELOPED FILM DRUM
TRANSMITTER
FACSIMILE SCANNER CAMERA

FIGURE 52

What can we accomplish in the way of power reduction by this technique? By these storage techniques we can go from this 10 billion watts to something in the order of 10 million watts, a very significant decrease in the power requirement.

The other area is the area of antennas. A very advanced vehicle might contain a steerable highly directional high frequency antenna, one which can beam most of the energy back to the Earth. None would be lost in other directions. And again, we have a television camera which can be pointed at a planet.

With systems such as this, where we can concentrate all of the energy in the direction we want, we can gain our most significant power reductions. This figure of 10 billion is then reduced to the order of a million watts.

A system which is perhaps still further in the future might involve a low frequency transmission system as shown in figure 53. There are certain advantages in going to low frequencies for the transmission of intelligence through space. However, we have the problem that low frequencies do not penetrate the Earth's ionosphere. This would require a relay satellite system outside the Earth's ionosphere to intercept these signals, change to a high frequency to bring them back to the Earth. This technique is quite a ways in the future.

Now what can we do if we combine several of these techniques? If we took the example of the nearly perfect receiver, the low noise amplifier, and had an airborne antenna of the type just described, we could get a continuous television picture in real time, that is an instantaneous picture from Mars with 10,000 watts—a large amount of power but not an unthinkable amount of power.

If we were interested in only a single picture and we combined the perfect receiver, the low noise amplifier, the airborne antenna and the storage technique we get down to very nominal amounts of power on the order of 10 watts. So we see that there are a great many things which can be done.

RESEARCH AND DEVELOPMENT REQUIRED

To review the situation and point up the research and development areas that have to be looked at to accomplish deep space communications, we have mentioned the recorders that give us high speed storage and then low speed playback of the picture, the storage videcon, tape recorders must be developed, and the facsimile photographic process is a possibility.

The low noise amplifiers, the masers and parametric amplifiers must have further work done on them. We need large ground antennas, to intercept the signals on Earth such as the Goldstone antenna which is approximately 85 feet in diameter. We need airborne antennas to concentrate the energy to the Earth. The low frequency communication and the use of a relay satellite system to get us through the Earth's ionosphere is a possibility. We need high-powered ground transmitters to communicate from the Earth to the space vehicle. We must develop high efficiency transistors so that we can make maximum use of the power that we do place aboard the space vehicle.

Power supplies, of course, must be developed. The more power that we can carry, the further we can communicate, and these power

ANTENNA SYSTEMS FOR SPACE PROBES
LOW FREQUENCY
LONG WIRE ANTENNA
RELAY SATELLITE
IONOSPHERE
STEERABLE HIGH
FREQUENCY ANTENNA

FIGURE 53

supplies will probably take the form of solar and nuclear energy converters.

The last area information theory, is one which is a highly theoretical area. It is one which promises s ill further reductions in the amount of power required. What is involved here is that most of the information which we try to transmit is redundant or not really useful. How do we extract only the useful data and send it and forget about all of the data which is not useful? If we can accomplish this, then we can reduce the power required for communications still further.

Figure 54 shows our requirements for communicating in space showing our Goldstone capabilities, both present and prospective. With the use of the Jodrell Bank radio telescope in England we hope to communicate with our latest space probe Pioneer V to a distance of 50 million miles.

DEEP SPACE COMMUNICATIONS

In addition to the flight and supporting programs described previously, the NASA has begun research and development in deep space communications. Studies have been initiated to determine communications requirements for lunar and planetary programs. In addition, investigation of components, techniques, and systems are being undertaken. The area of deep space communications is extremely broad, covering many forms of data transmission, and it is in the early stages of growth. Considerable research will be required in order to better understand the problems which might be encountered in establishing reliable communications in these hitherto unexplored regions.

GEODESY

By Benjamin Milwitzy, Head, Geodetic and Navigational Satellites Program, NASA

A properly instrumented Earth satellite ("geodetic satellite") can greatly improve existing knowledge and provide new knowledge in a number of areas in geodesy and geophysics, such as:

1. Accurate determination of the zonal and, probably, also the tesseral harmonics in the expansion of the Earth's potential field. (The latter possibility stems from the high resolution which can be obtained from observations of a properly designed geodetic satellite.) This will allow greater precision in the prediction of satellite and space-vehicle trajectories and will provide the data required for the precision computations used in the guidance of space vehicles.

2. Improved knowledge of the size and shape of the Earth, which will provide a basis for more precise geodetic controls and greater accuracy in mapping, as well as a basis for additional theoretical work on the internal structure of the Earth.

3. Location and measurement of large gravity anomalies. These measurements will greatly extend and fill in large gaps in the coverage of terrestrial gravimetry. They will provide an overall check and tie together existing surface gravity studies and those to be made in the future. They will be particularly useful for detecting systematic errors in terrestrial gravimetry.

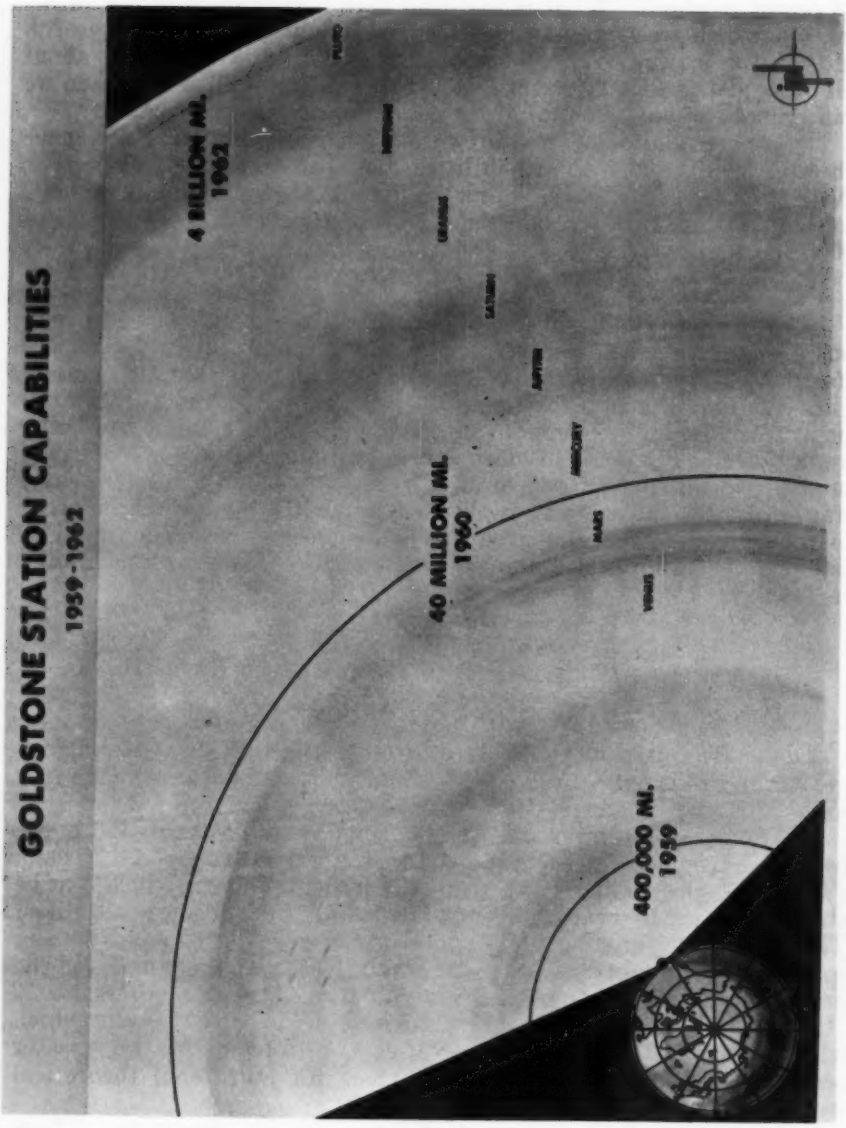

GOLDSTONE STATION CAPABILITIES
1959-1962
4 BILLION MI.
1962
40 MILLION MI.
1960
400,000 MI.
1959
PLUTO
NEPTUNE
URANUS
SATURN
JUPITER
MERCURY
MARS
VENUS

FIGURE 54

4. Strengthening of existing triangulation networks.
5. Improved interdatum connections.
6. More accurate location of individual datums with respect to the gravitational center of the Earth, the polar axis, and the meridian of Greenwich.
7. If a sufficient number of observation stations are provided, the establishment of a unified worldwide datum accurate to within 60–100 feet.
8. Improved locations of specific points on the Earth's surface, oceanic islands and points in remote areas with respect to existing data.
9. The use of dynamical methods of analysis of the data from a geodetic satellite should permit a more precise determination of the mass of the Moon and the location of the gravitational center of the Earth-Moon system.
10. Annual, secular, and relativistic, perturbations of satellite orbits might also be derived from a long-lived geodetic satellite.

In more general terms, a geodetic satellite can provide us with a more accurate determination of the size and the shape of the Earth, it can help us establish more precisely the distances between continents and the positions of oceanic islands, and it can help us strengthen existing triangulation networks.

FIGURE 54

SIZE AND SHAPE OF THE EARTH

There are many reasons why the size and shape of the Earth are important to us; among these are the following:

Every long-range mapping problem involves the size and shape of the Earth as fundamental parameters. In mapping we need a reference surface or datum on which to project all horizontal measurements and from which all elevations can be figured; this datum is the "figure of the Earth." Thus, the basic geodetic reference for mapping provides the major requirement for accurate data on the size and shape of the Earth.

The shape of the Earth also, in a sense, represents the shape of the Earth's gravitational field. This has an important bearing on the flight of ballistic missiles, space vehicles, and satellites.

Thirdly, the shape of the Earth gives us extremely important clues to the structure and strength of the interior of the Earth.

When we say "shape of the Earth," or "figure of the Earth," we don't mean the topography of the Earth. What we really mean is the surface of mean sea level, which is called the geoid. On figure 55 the geoid appears as a rather wiggly line. This is because the sea level surface is pulled up and down by variations in the mass attractions from place to place.

Now, for mapping purposes, because many calculations are involved, we need a mathematical model to represent the Earth, and for this purpose we generally use an ellipsoid of revolution. This is what you get when you take an ellipse and rotate it about its short axis.

The problem that we run into is this: The force of gravity is normal to the geoid and not normal to our reference ellipsoid, and this difference gives rise to a troublesome error called the deflection of the vertical. We thus find ourselves in a somewhat embarrassing situa-

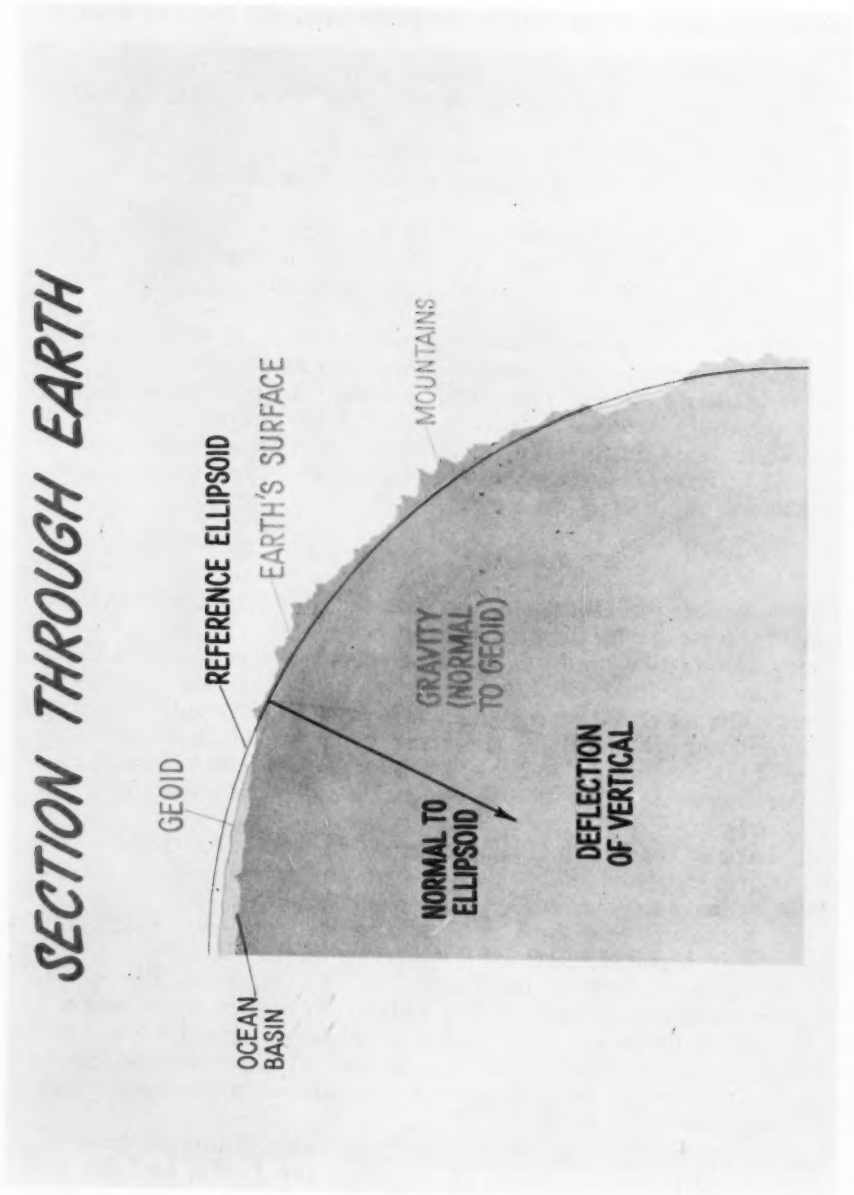

SECTION THROUGH EARTH
GEOID
REFERENCE ELLIPSOID
EARTH'S SURFACE
MOUNTAINS
GRAVITY (NORMAL TO GEOID)
NORMAL TO ELLIPSOID
DEFLECTION OF VERTICAL
OCEAN BASIN

FIGURE 55

tion. All of our geodetic measurements are tied to gravity, but all of our mapping has to be based on a reference ellipsoid. In order to determine the reference ellipsoid which best fits the geoid everywhere, we have to know the shape of the geoid. We also have to know the differences which exist between these two surfaces at all points.

The fact that the geoid is always perpendicular to the force of gravity means that it is really a surface, not only of the Earth, but of the gravitational field surrounding the Earth, and any distortions or irregularities in this surface are reflected in similar distortions and similar irregularities in the gravitational field of the Earth. Thus, if we have a satellite in such a gravitational field, its orbit will be distorted or perturbed by these irregularities in the gravitational field. And we can use just these distortions to work backwards and determine what is the shape of the geoid that produced the observed perturbations of the satellite orbit.

EFFECT OF EARTH'S SHAPE ON SATELLITE MOTION

To give an example, there are two types of perturbations caused by the oblateness flattening of the Earth. These are illustrated in figure 56. In the first case, the perturbation is essentially a rotation or precession of the plane of the orbit of the satellite. The shaded area represents the plane of an elliptical orbit at a given time. At the top of the figure is the apogee, the point farthest away from the surface of the Earth; and at the bottom is the perigee, the point closest to the Earth. Between the two we have the major axis of the ellipse, which is called the line of apsides.

At a later time, because of the excess pull of the bulge of the Earth each time the satellite comes around, the plane of the orbit has rotated to a new position, shown by the second shaded area. One way to describe this precession is as follows: While the line of apsides maintains a constant inclination to the equatorial plane, the apogee goes around in a circle and the perigee goes around in a circle; thus, the line of apsides swings and the plane of the orbit rotates slowly in space.

A second type of motion due to the Earth's oblateness occurs within the plane of the orbit; this is a motion in which the line of apsides itself rotates slightly from one revolution to the next.

Both of these motions occur at the same time. After a time, the plane of the orbit has precessed around to the new position and, in addition, the apogee, instead of being at the top of the figure, has rotated around to the bottom of the figure.

It is possible, by analyzing such orbital perturbations, to determine improved values for the shape of the Earth.

In the case of the Vanguard I satellite, 1958 Beta, analysis of just this type of motion yielded new data on the shape of the Earth. These data show that the flattening is not quite as much as was previously believed, and this has implications on our ideas regarding the strength of the inner structure of the Earth. It indicates that the Earth is perhaps a little more rigid in its interior than we previously thought.

Other types of orbital pertubations also exist, and can give us further information on the shape of the Earth. For example, it was

EFFECTS OF EARTH'S OBLATENESS
APOGEE
LINE OF APSIDES
PLANE OF EQUATOR
LINE OF NODES
PERIGEE
REGRESSION OF NODES
A1 A2 A3
P3 P2 P1
PROGRESSION OF LINE OF APSIDES
APOGEE
PERIGEE
PERIGEE
APOGEE
COMBINED MOTION

FIGURE 56

noticed that the perigee altitude of the Vanguard I was not constant but varied periodically with time; working this data back gave an indication of the finer distortions of the geoid which are superimposed on the basic ellipsoidal shape. This is shown in figure 57. For clarity, they are grossly exaggerated. This is what has given rise to the term "pear-shaped" Earth. It should be noted that actually there are only slight differences in the new shape of the geoid from the basic ellipsoidal form.

Such studies give us additional information about the structure of the Earth, and about the gravitational field of the Earth. The important thing here is that the mantle of the Earth cannot be plastic, if such a "pear shape" exists. If it were completely plastic the shape would have to be symmetrical about all three axes. The fact that it is not is an indication that there is structural strength in the mantle, and calculations based on these observations make it appear that this strength must be just about the same order as that of building brick.

GEODETIC CONNECTIONS

To go on to the second area where the satellite can provide previously unobtianable knowledge about the Earth, let us consider the problem of intercontinental distances and the locations of islands.

By using the conventional methods of surveying, tied together with astronomical observations, it has been possible to establish in many areas over the Earth, intricate and very accurate geodetic networks. For example, in the North America net, one can essentially determine distances over 3,000 miles with accuracies of the order of 75 feet. The same is true for points connected to European datum. The major world triangulation networks are shown in figure 58.

Now, these surveying methods, unfortunately, fail when we get to large bodies of water. We cannot use the short base lines over water that we use over land, and so the distances between the continents and the positions of some islands are not very accurately known. The satellite provides us with a powerful tool to determine such distances, since it gives us a triangulation point high up in the sky.

OBSERVATION TECHNIQUES

There are basically three methods which can be used to observe a geodetic satellite.

If the satellite contains a flashing light of high intensity, this flashing light permits us to photograph the satellite against the star background. We can obtain the desired geodetic data by any of three separate techniques: The first is the geometric method of simultaneous observations. The second is the orbital extrapolation method. The third may be termed "dynamical analysis." These are indicated on figure 59.

With the geometric method, the light flashes, and at that instant photographs are simultaneously taken from several points on one geodetic net and several points on the other geodetic net.

In the photographs we have the stars as a background, and the apparent position of the flashing light against the steller background gives us a line in space which connects the celestial sphere, the satellite,

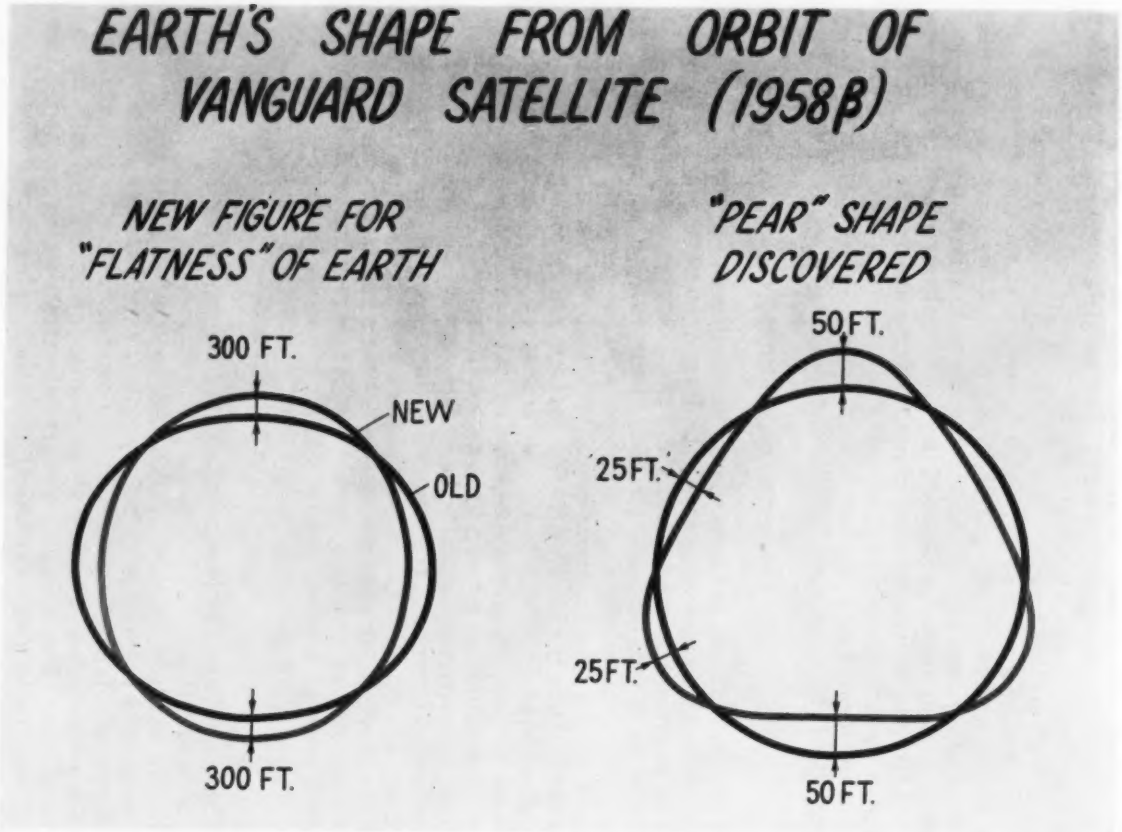

EARTH'S SHAPE FROM ORBIT OF VANGUARD SATELLITE (1958β)
NEW FIGURE FOR "FLATNESS" OF EARTH
300 FT.
NEW
OLD
300 FT.
"PEAR" SHAPE DISCOVERED
50 FT.
25 FT.
25 FT.
50 FT.

FIGURE 57

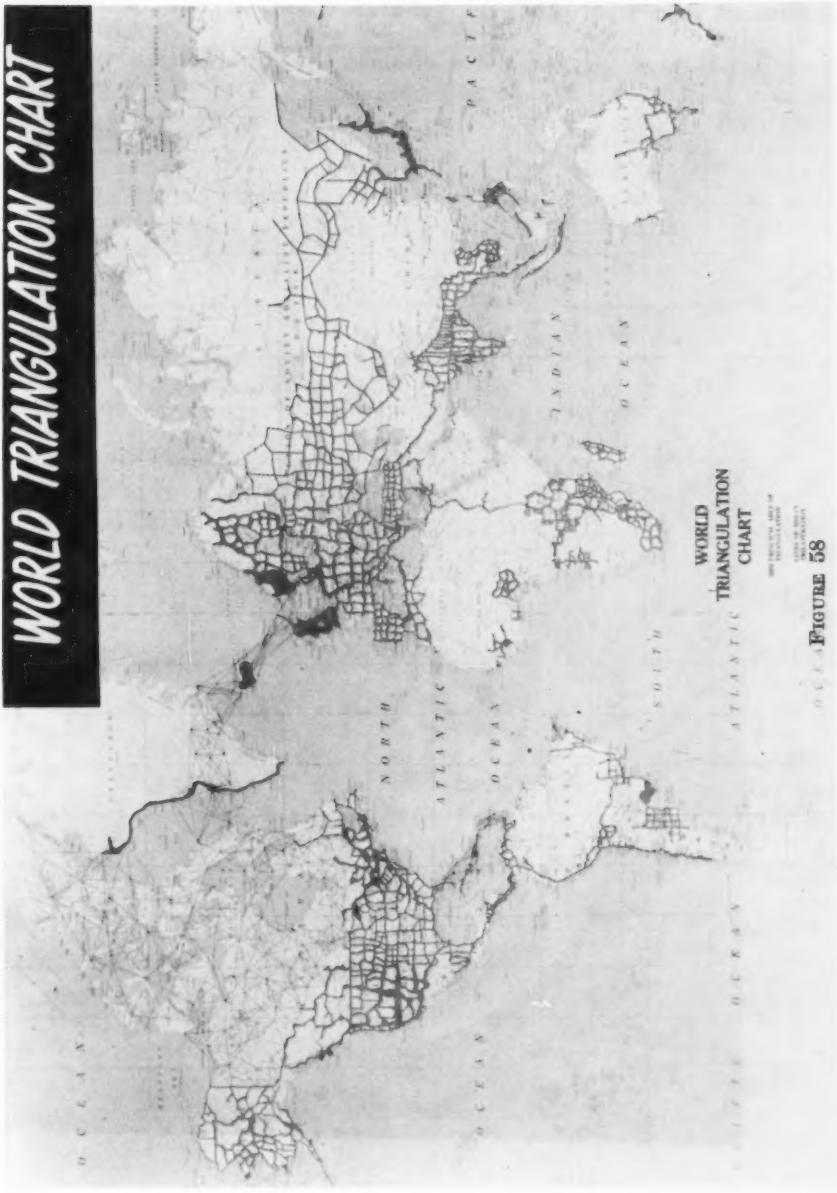


FIGURE 58

FIGURE 57

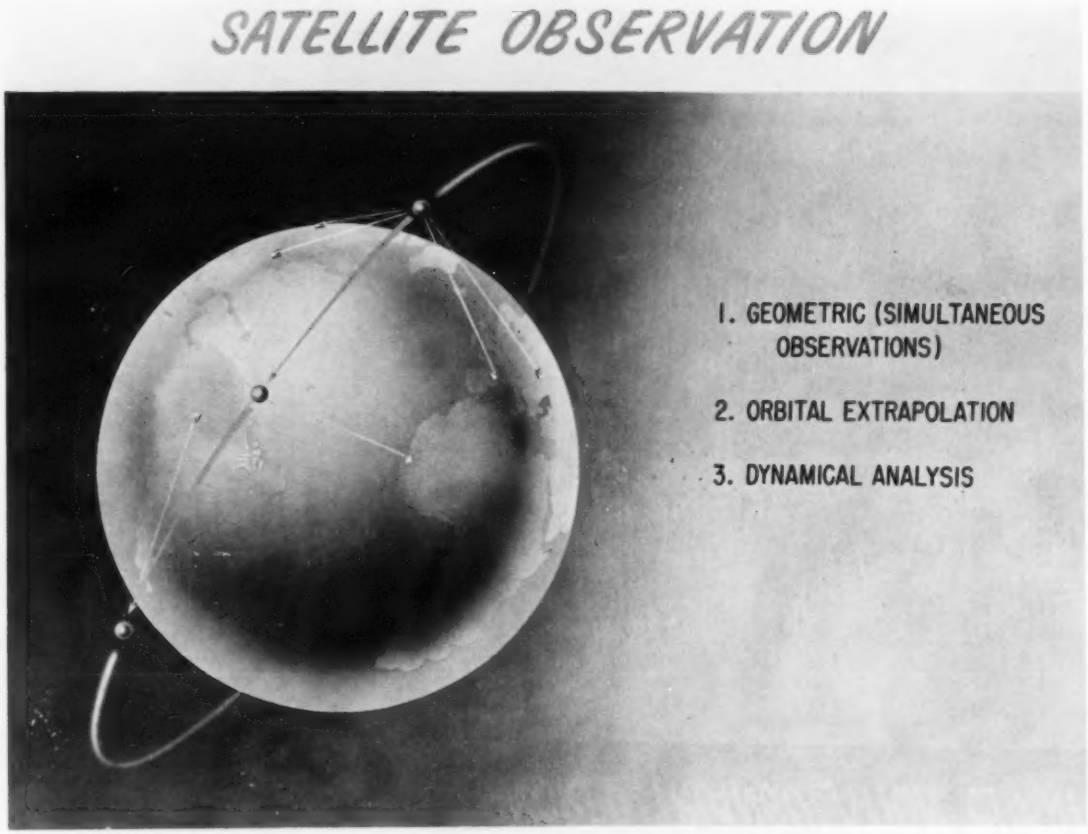


FIGURE 59.—Methods of observing a geodetic satellite.

and the observation point. We then have all of the ingredients required to perform a three-dimensional triangulation which will tell us the distances and the orientations of these two nets, one with respect to the other. This method does not require information on the orbital characteristics.

The second method is one which you would have to use if you were trying to tie together two nets when it is not possible for stations on both nets to see the satellite at the same time. In such a case, we use the orbit as an extrapolation device to connect the two observations.

One of the beautiful features of these techniques is that by using the stars we completely rid ourselves of any dependence on the local vertical, and therefore avoid the error due to the deflection of the vertical.

In the third type of analysis, we determine the orbit. We set up the equations of motion for the system in which the gravitational parameters are treated as unknowns, and we calculate what the gravitational terms have to be to account for the observed motion. The Vanguard I results mentioned previously, associated with the new figure of the Earth, were obtained by this type of dynamical method.

Similar types of analyses can be made if range measurements are obtained between the satellite and appropriately located ground stations. The recent development of small, lightweight, and low power-consuming electronic ranging transponders makes possible the augmentation of optical observation techniques by electronic ranging methods.

GEODETIC SATELLITE

Figure 60 is intended to give an idea of what a geodetic satellite might look like. It is a relatively simple thing in concept: A fairly high density sphere weighing about a hundred pounds, being perhaps 21 inches in diameter, and equipped with a number of extremely high-intensity discharge lamps. The satellite will contain electrical equipment to operate these lamps, a timer, and a radiobeacon transmitter. The radiobeacon transmitter will be used for tracking purposes and to provide acquisition data for aiming the cameras. An electronic ranging transponder would enhance the usefulness of the satellite and would probably be included in the instrumentation. The satellite also contains storage batteries and solar cells to recharge the batteries.

By using satellites of this type, it should be possible to connect all of the geodetic nets and establish a unified datum with an overall accuracy of 60 to 100 feet.

GEODETIC SATELLITE

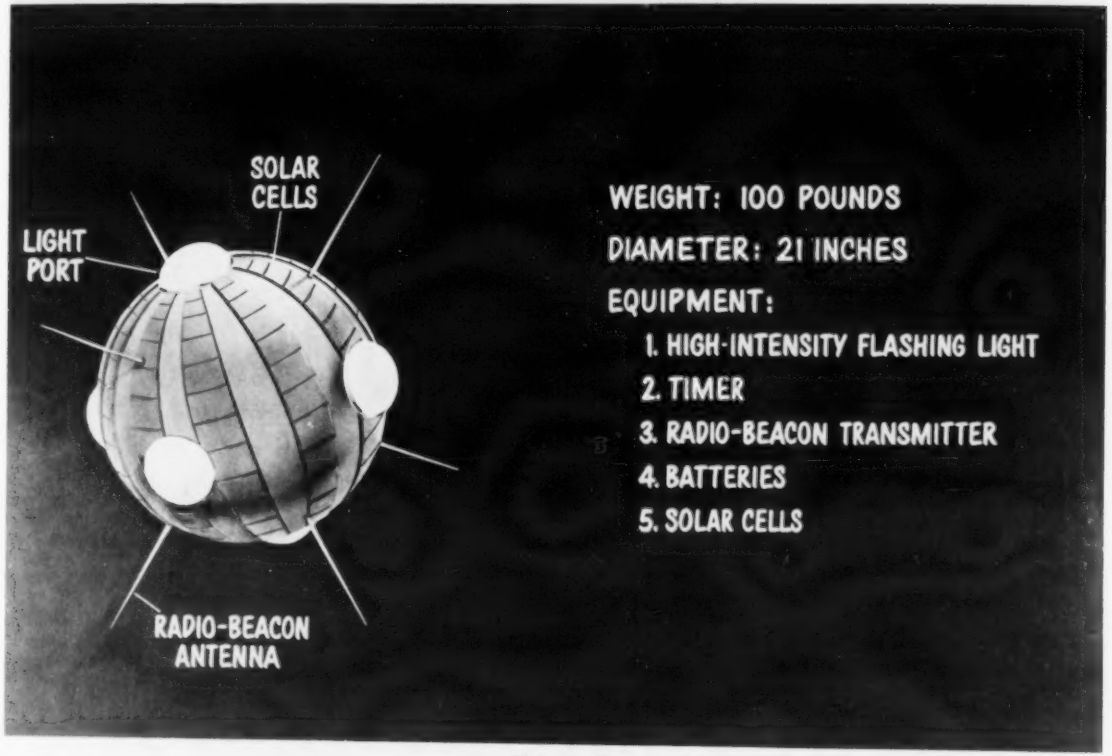


FIGURE 60

III. MANNED SPACE FLIGHT

By George M. Low, Chief, Manned Space Flight Program, NASA

Our long-range plans for the exploration of space are based on the premise that man will actively participate in many of our space missions. These plans, therefore, strongly depend on the assumption that manned space flight is feasible, and that man will indeed be able to perform useful functions in space. Much of our future effort depends on the validity of this assumption, and it is therefore imperative that man's capabilities in space be determined as soon as possible.

PROJECT MERCURY

Project Mercury was conceived, and is being carried out, in a manner that will attempt to achieve manned orbital flight at the earliest practicable date. Its primary objective is to determine man's capabilities in a space environment.

GENERAL DESCRIPTION

Mercury capsule system

The Project Mercury capsule, or satellite system, is illustrated in figure 61. This system consists of the ballistic capsule, fitted with a retrograde and separation rocket package, an escape rocket pylon and an emergency escape rocket. The retrograde and separation rocket package contains small, solid propellant rockets used first to separate the capsule from its booster and later on to initiate the descent of the capsule from its satellite orbit. The emergency escape rocket, mounted on top of the escape rocket pylon, serves the function of separating the capsule from the booster and carrying it away from the booster, should a booster malfunction occur. The aerodynamic spike, pictured on top of the emergency escape rocket, is used to minimize the aerodynamic drag forces during the ascent trajectory.

Ballistic capsule

The ballistic capsule is illustrated in figure 62; the capsule has high aerodynamic drag in order to minimize the reentry heating. It will reenter the atmosphere with the large, blunt end facing forward. The heat of reentry will be dissipated by an ablation heat shield. As mentioned earlier, the descent from orbit of the capsule will be initiated by a cluster of solid propellant retrorockets which are normally affixed to the heat shield. Parachutes are provided for the final stages of the descent.

In orbit, the capsule's attitude is sensed by an infrared horizon scanner, while attitude control is achieved by small reaction jets.

Within the pressure-tight capsule, the pilot is supported in a form-fitting couch. Centrifuge tests at the Navy's Johnsville facility have

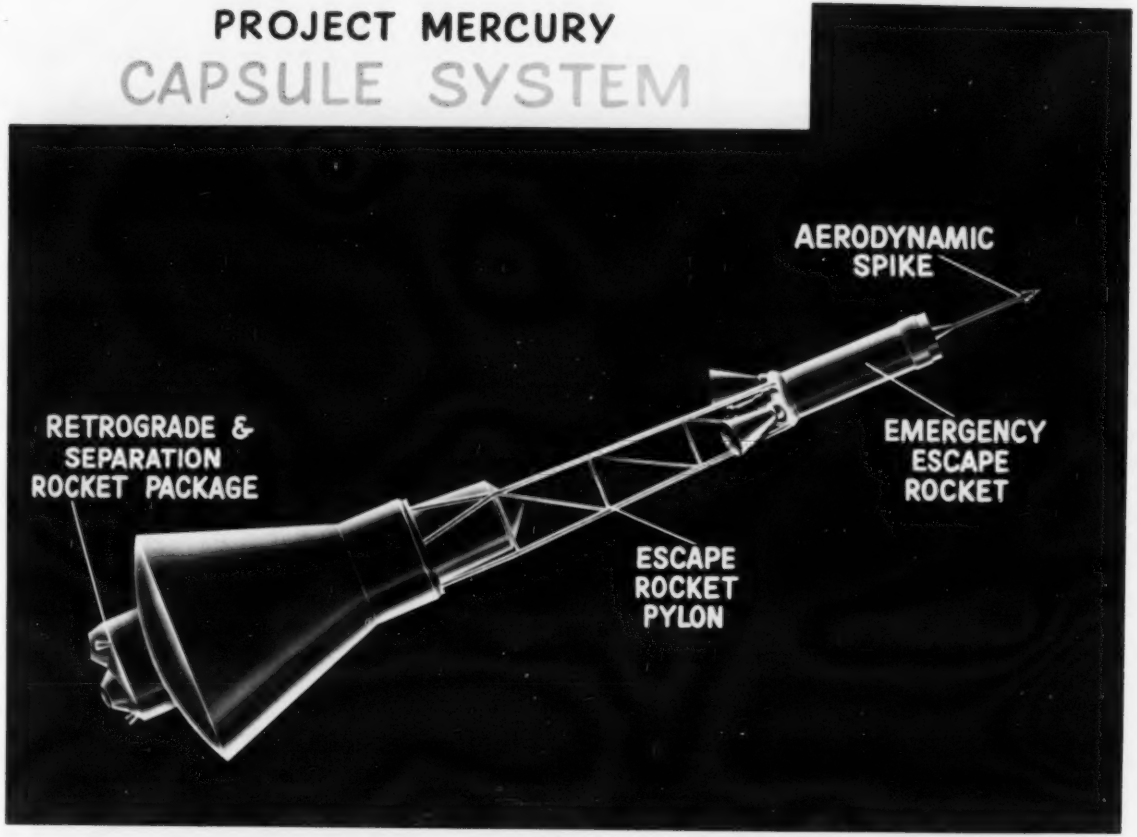


FIGURE 61.—Project Mercury—Capsule System.

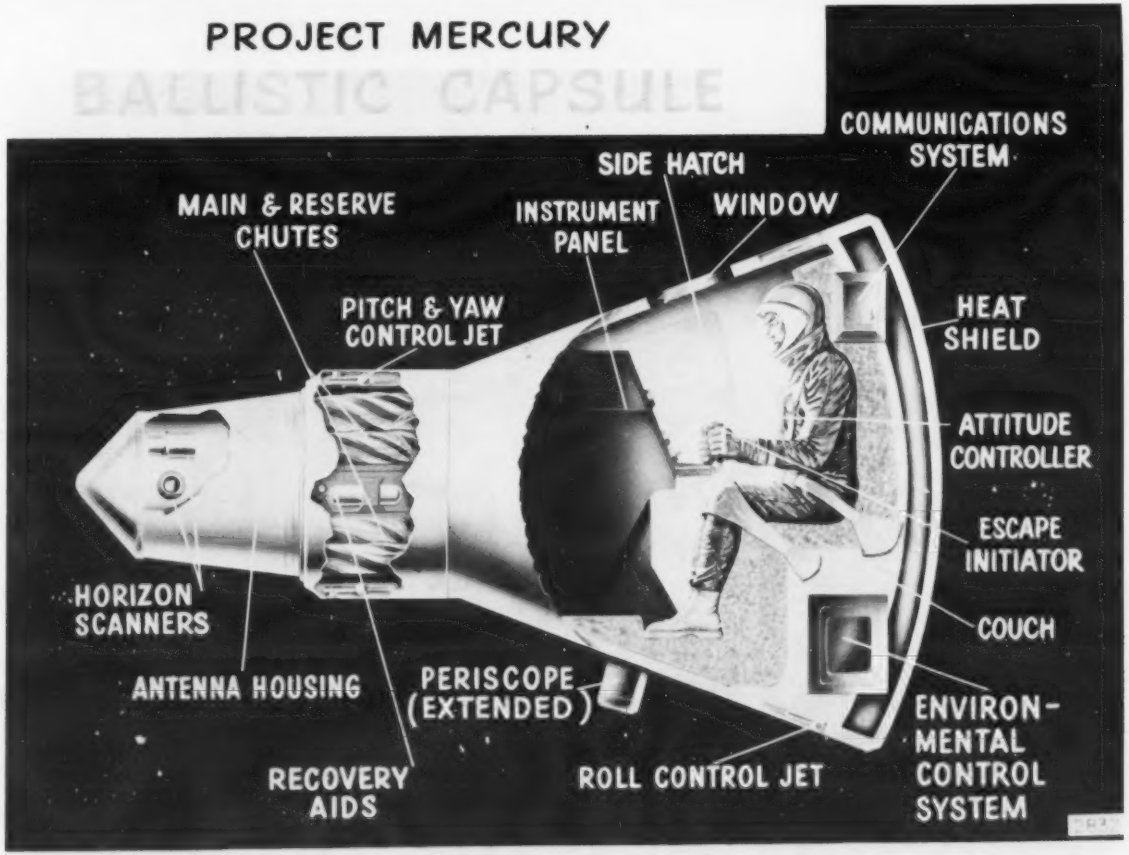


FIGURE 62.—Project Mercury—Ballistic Capsule.

demonstrated that in such a couch man can withstand considerably more than the maximum accelerations and decelerations he will encounter in flight.

An environmental control system will maintain the cabin's atmosphere within prescribed limits; a communications system will telemeter important data to ground stations in addition to permitting voice communication between the pilot and the ground.

Pictorially, this sketch indicates that the capsule is a relatively simple vehicle; but such is not the case. It has been a major engineering task to design a satellite that can withstand the heat and forces of launch and reentry, and yet is light enough to be boosted into orbit. The design of reliable subsystems, sufficiently small to fit within the six-foot diameter capsule, has stretched the existing state of the art. The complexity of the device is perhaps best illustrated by the fact that 7 miles of electrical wiring are interwoven into the capsule in order to control the many valves, rockets, explosive bolts, and electronic systems.

Pilot's instrument panel

There has been a great deal of discussion concerning the role to be played by the pilot in a space mission. We are firmly convinced that this role should be a very active one, and that the reliability of all systems will be greatly enhanced by the capabilities of the astronaut.

The extent of pilot participation in the Mercury operation is illustrated with the aid of a picture of the pilot's instrument panel, shown in figure 63.

The sequence controls, on the panel to the left of center, allow the pilot to back up essentially every function that is normally performed automatically in the flight sequence. For example, if the retrorockets do not fire at the proper time, the astronaut can fire them by pushing the proper button.

On the extreme left panel are the switches used to lock out the automatic attitude control system and to activate the manual control system. Then, by using the manual control stick together with the flight instruments, the pilot can maintain the capsule in the proper orientation.

Another handle on the left-hand panel allows the astronaut to decompress the capsule in case there is a fire or a buildup of toxic gases. Venting the capsule to the outside vacuum will extinguish a fire or remove noxious gases. A second handle is provided for repressurization.

The panel on the right contains instruments and switches for the control of the life-support, electrical and communications systems; and warning lights that indicate the malfunctioning of any of these systems.

The entire array of instruments illustrates that the astronaut's participation in the Mercury mission will be very extensive.

Flight trajectory

A typical flight trajectory is illustrated in figure 64. The manned satellite will be launched from Cape Canaveral with an essentially unmodified Atlas booster. The first illustration in the sequence in figure 64 shows the Atlas with the capsule and the escape system

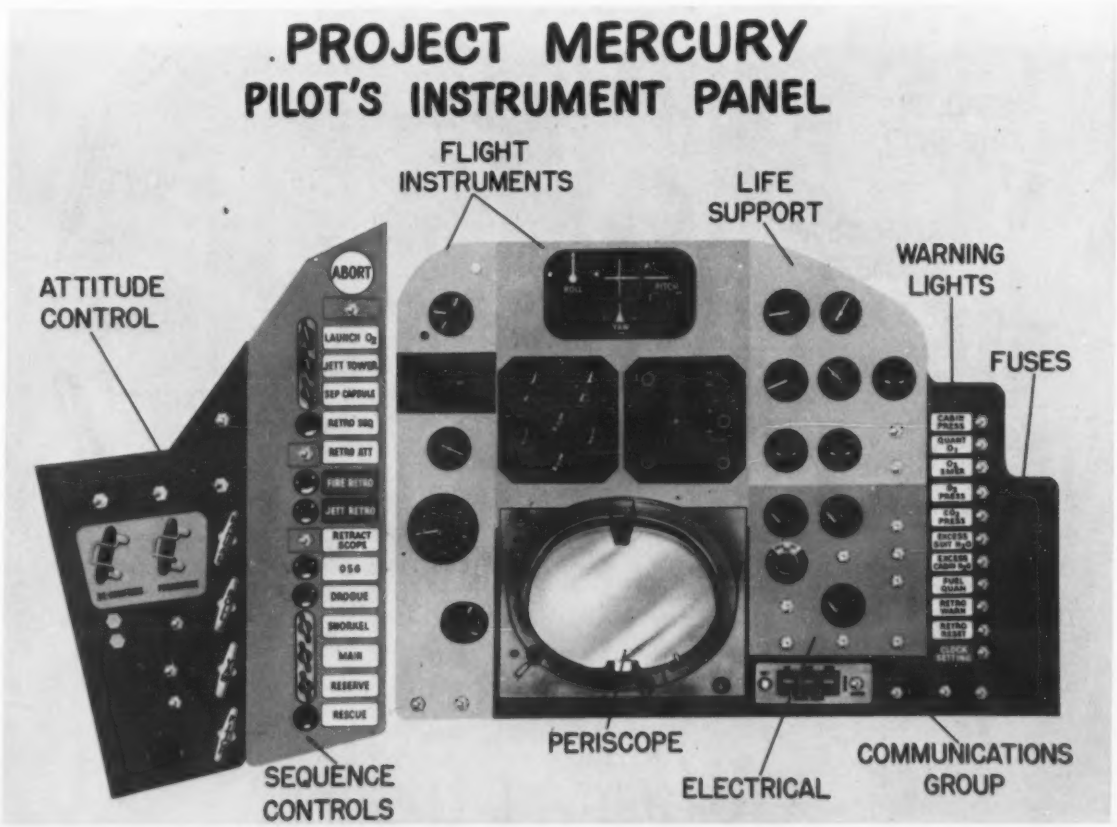


FIGURE 63.—Project Mercury—Pilot's Instrument Panel.

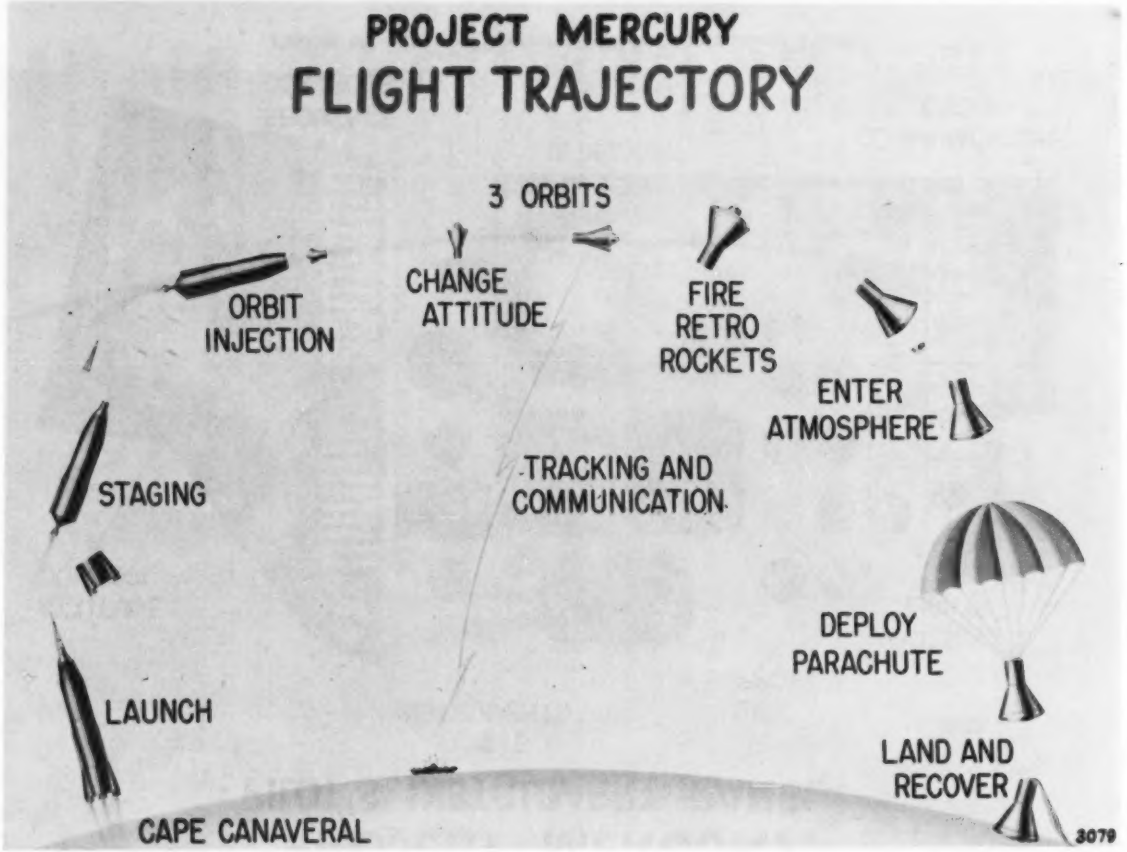


FIGURE 64.—Project Mercury—Flight Trajectory.

mounted on top of it. The use of the escape system will be described later.

In a normal launch, the escape system will be jettisoned shortly after Atlas staging; after staging, the Atlas has left the atmosphere and the danger of a high-order explosion has been eliminated. An escape after staging would be executed by shutting down the Atlas and separating the capsule with the small separation rockets normally used at orbit injection. Jettisoning the escape system at staging also avoids lifting unnecessary weight into orbit.

Normally, the Atlas carries the satellite into orbit, where separation is accomplished with small separation rockets mounted on the capsule. The attitude control system will then aline the capsule in a heat-shield-forward position. While in orbit, the capsule will be tracked and periodic communication with ground stations will be possible.

After a predetermined number of orbits, the retrorockets will slow the capsule by about 350 miles per hour to put it into a shallow descent trajectory toward the atmosphere; the retrorockets are then jettisoned.

Atmospheric entry must be made at a very shallow angle in order to minimize the decelerations. In a normal reentry, the peak deceleration is about 9 g. or about the same as a peak acceleration during boost. After the capsule has been slowed to near sonic speed by atmospheric drag, a drogue 'chute is deployed to minimize subsonic oscillations. Final descent is accomplished by a large parachute designed to give a landing speed of 20 miles per hour. A water landing is programed.

Escape system

One of the most important components of the Mercury system is the escape system. It is well recognized that, without a highly reliable escape system, it would not be possible to attempt a manned space flight mission in the time period of the next few years. Consequently, a great deal of effort is being spent on the design and qualification of an escape system which can carry the manned capsule away from the Atlas should the booster malfunction. The escape system consists of a tower above the capsule supporting a solid fuel rocket that exhausts through canted nozzles to the rear. The escape sequence is as follows:

1. The capsule is disengaged from the booster and simultaneously the escape rocket is fired.
2. The escape rocket pulls the capsule forward and to the side of the booster to a distance of at least 200 feet in 1 second.
3. The capsule and tower coast until they slow down; the tower is then jettisoned and a normal parachute-sequence landing is begun.

RESEARCH AND DEVELOPMENT PROGRAM

Because the ultimate achievement of manned orbital flight will constitute a stretching of the existing state-of-the-art, its accomplishment requires an extensive research and development program. For flight within the atmosphere, the Mercury capsule must be stable over the widest speed range yet encountered by any vehicle—from satellite velocity to a very low impact speed. And, in orbital flight,

all its systems must function properly in the weightless state. The capsule must be compatible with the launch rocket and must be at home in the water while awaiting recovery. A development program of this magnitude requires the use of many different facilities and techniques.

Wind tunnel testing

The Mercury capsule shape was determined from intense scientific and engineering investigations using a wide variety of technical equipment. In the wind tunnel testing program, Mercury experiments were performed in 26 different wind tunnels of the National Aeronautics and Space Administration, the armed services, and the aircraft industry. Seventy separate models of various sizes and configurations were built and 106 tests were conducted. During these tests, the aerodynamic coefficients, stability derivatives, and heating characteristics were determined for the capsule less booster, with and without the escape tower; and the capsule in combination with the Little Joe, Redstone, and Atlas boosters. Figure 65 shows a model of the Mercury capsule, together with its escape tower, installed in a supersonic wind tunnel.

Full-scale capsule models

Wind tunnel tests alone are insufficient to solve all of the many problems associated with the Mercury flight systems. A flight test program, using full-scale capsule models, was therefore initiated; these "boilerplate" models, which are made in NASA's own shops, duplicate fully both the weight and external shape of the final Mercury operational capsules. Boilerplate capsules in various stages of fabrication are shown in figure 66; their construction is greatly simplified through the use of heavy, welded sheet-metal. They do not include many of the Mercury systems, such as the life-support system or the communications system. The boilerplate capsules have been used to develop the parachute system, to validate recovery procedures, to check the functioning of the escape system and to determine the motions and heating of the capsule during reentry.

Airplane drop tests

The Mercury flight test program included airplane drop tests in which full-scale capsule models were dropped from large cargo aircraft at high altitudes. In these tests, the capsule is pulled out of the airplane's cargo door on a sled. As soon as it is clear of the aircraft, the sled is released and, after a period of free fall, the small drogue parachute is ejected by a mortar charge. This parachute reduces the capsule's swinging motions in the early stages of descent. At a predetermined altitude, the small parachute pulls the top antenna housing away from the capsule and automatically deploys the main descent parachute illustrated in figure 67. This parachute is a 63-foot, ring-sail-type, cargo parachute. Upon impact on the water, the parachute is released from the capsule by a small explosive charge to avoid dragging of the capsule by the wind; figure 68 illustrates the moment of impact. After impact, the capsule models are recovered by helicopter as shown in figure 69, and returned for further use.

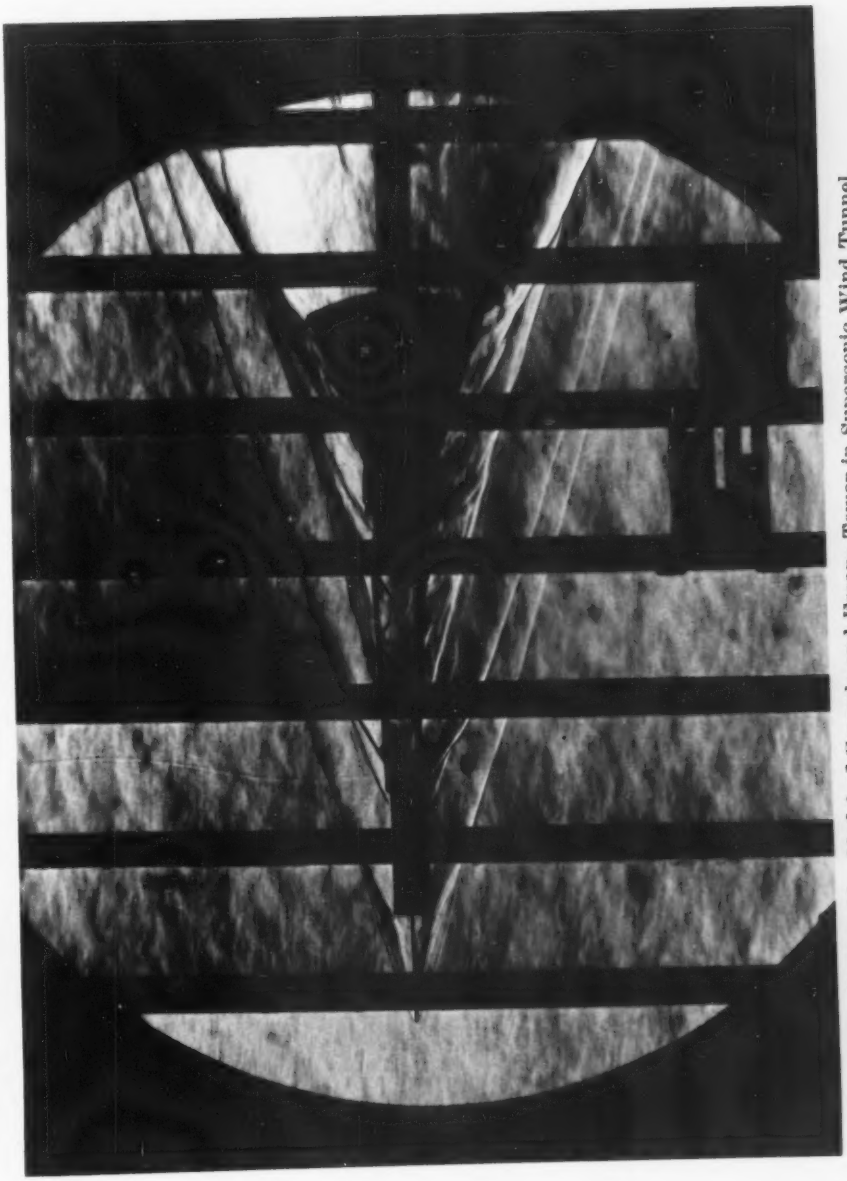


FIGURE 65.—Model of Capsule and Escape Tower in Supersonic Wind Tunnel.

FIGURE 66.—Full-scale Capsule Models in Various Stages of Construction.

FIGURE 67.—Airplane Drop Test of Mercury Capsule.

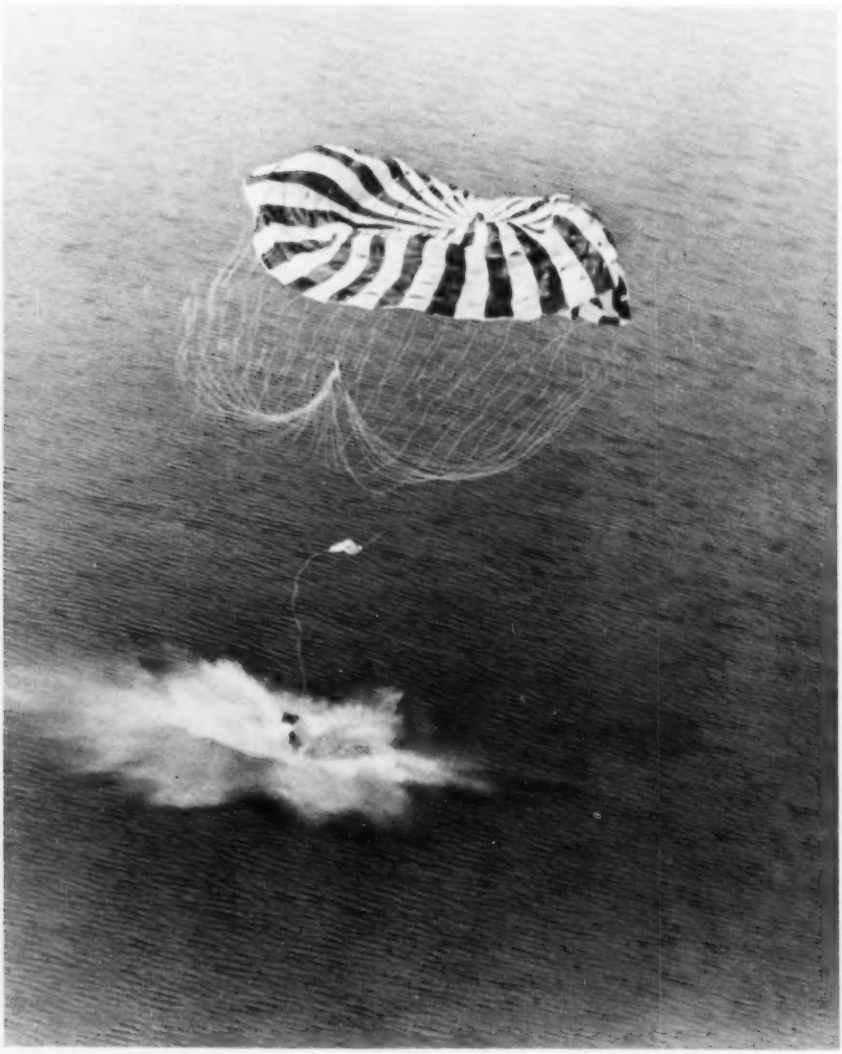


FIGURE 68.—Capsule Impact After Drop Test.

FIGURE 69.—Helicopter Pick-up of Capsule Following Drop Test.

In other parachute development tests, capsule models were released from fighter aircraft at supersonic speeds to develop and qualify the capsule's drogue parachute. To date, 122 capsule models have been dropped from airplanes in the parachute development program, in order to develop a highly reliable parachute system.

Escape system tests

Concurrent with the airplane drop tests, an extensive rocket flight test program has been initiated. At NASA's launch site at Wallops Island, Va., tests were performed to develop the emergency escape system and to qualify it for future use on manned flights. As illustrated in figure 70, escape from the launching pad can be simulated by lifting the capsule from the ground with the escape rocket as the only means of propulsion. After ignition, the escape rocket burns for only one second. The capsule and tower then coast together to the peak of the trajectory. At a maximum altitude, the tower is separated from the capsule with a small rocket. Then the drogue parachute is ejected by a mortar charge. After the swinging motions of the capsule have been reduced, the drogue parachute and the antenna housing are jettisoned, automatically deploying the main parachute.

In an off-the-pad abort, the capsule reaches an altitude of more than 2,000 feet. The main parachute is deployed and opened fully at about 1,000 feet, providing ample time for the use of the reserve safety parachute if required. In these tests, capsules were recovered by helicopter and returned to Wallops Island for further use in the test program.

The tests also provide an opportunity to conduct development work on the recovery and pickup techniques.

Little Joe booster

Other flight tests are being carried out with a series of booster vehicles of increasing size and capabilities. A solid propellant-rocket booster, nicknamed "Little Joe," was designed and fabricated especially for Project Mercury. This booster develops ¼-million pounds of thrust at takoff.

Final assembly of the booster at Wallops Island is illustrated in figure 71. The capsules used in the early phases of the Little Joe program were manufactured in NASA's shops and do not contain many of the systems and subsystems that will be part of the Mercury operational capsules. The escape tower and rockets, however, are final production hardware, being qualified in the Little Joe program.

To date, four Little Joe vehicles have been launched successfully. The first was a test of the basic booster system. In a second and fourth test, the escape mechanism was activated intentionally during the early phases of flight. These tests simulated a severe escape condition that could occur in an orbital flight launch. The capsules were recovered, undamaged, shortly after landing. The third flight was used to perform an escape maneuver at high altitude. After a planned escape, the capsule coasted to an altitude of 55 miles and was recovered 200 miles from the launch site.

On the last two Little Joe flights, a small monkey was in the capsule, and was recovered alive and well at the end of the flight. Figure 72 shows the picture of the monkey, nicknamed "Sam," in its supporting

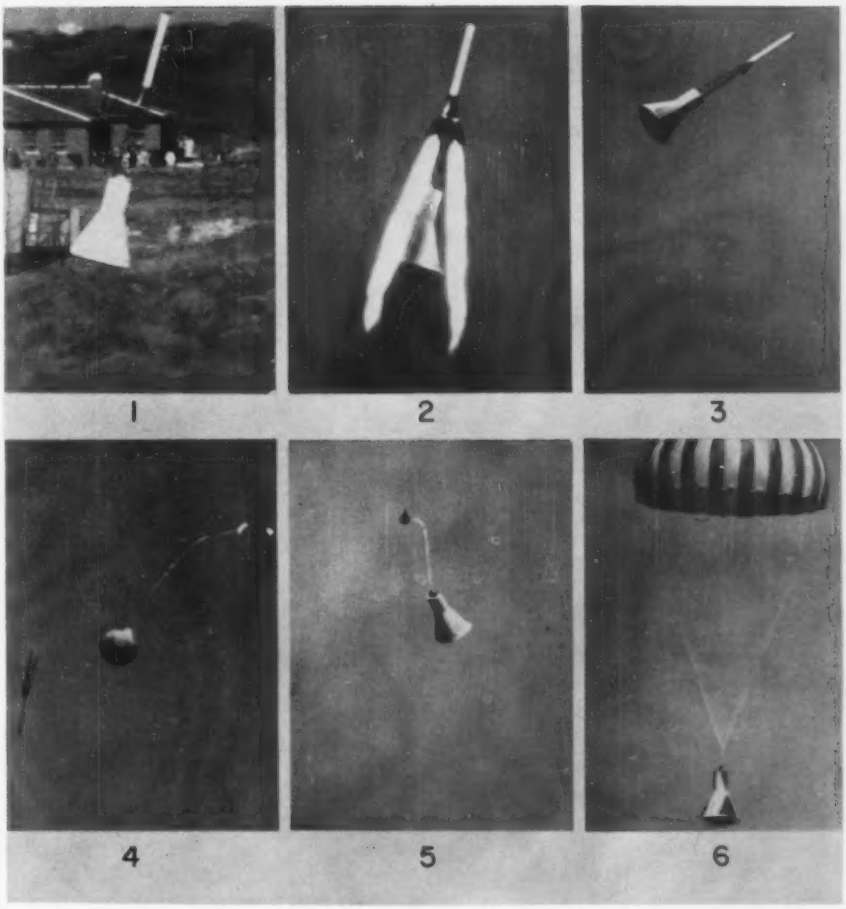


FIGURE 70.—Off-the-pad Abort Test of Escape System.

FIGURE 71.—Assembly of Little Joe Vehicle.

FIGURE 72.—Monkey in Supporting Couch Prior to Flight, with Dr. W. Lynn Brown of the University of Texas.

couch. "Sam" was trained for his flight by psychologists at the University of Texas.

Figure 73 shows the Little Joe booster together with the Mercury capsule shortly after takeoff. On takeoff, two large solid-propellant Castor motors and four small Recruit motors are ignited. The small Recruits burn for only one second, while the Castors have a burning time of 27 seconds. A second pair of Castors is ignited just before burnout of the first pair, at a high altitude. Later on in the flight, the escape rocket is ignited and separates the capsule from the booster.

At the completion of the escape sequence, the capsule falls back toward the ocean and parachutes are deployed. Recovery, as accomlished by Navy ships, is shown in figure 74.

The Little Joe test, together with the escape system tests described in the preceding section, have demonstrated the use of the Mercury escape system under many different conditions that might be encountered when the manned capsule is launched into orbit.

Big Joe flight

The Atlas booster was used in the most severe test of the Mercury system that has been performed to date. In that test, a research and development version of the capsule was launched from Cape Canaveral. In contrast to the Little Joe vehicle, the combination of the developmental Mercury capsule with the Atlas booster was nicknamed "Big Joe."

The trajectory for the flight was shaped to simulate the return from orbit without actually going into a satellite orbit. The objectives of the Big Joe flight test were to check the capsule's heat protection at nearly orbital speed; to verify its aerodynamic stability; to provide a severe test of the onboard recovery system; and to develop recovery procedures in a realistic test situation. A picture of the Big Joe capsule, as it is hoisted to the top of the gantry, is shown in figure 75. Within the capsule, special instrumentation is provided to measure the loads, noise, motions, and temperature during flight; and a control system is installed to orient the capsule into the proper attitude after separation from the booster. The bottom of the capsule is fitted with a plastic heat shield designed to dissipate the tremendous heat of reentry.

Figure 76 shows the capsule and the booster together several days prior to the launch. During that time, all the capsule and booster systems were checked and rechecked, and the functioning and readiness of thousands of component parts were recorded; the malfunctioning of any one of these parts could make the difference between a successful flight and a complete failure.

The launch, shown on figure 77, was made in the early morning hours so that a full day would be available for the recovery operations, if required. The Atlas booster carried the capsule to an altitude of 100 miles and to nearly orbital speed. The Big Joe capsule was then separated under conditions that closely simulated orbital reentry. On the recovery ships, the capsule appeared as a flaming fireball as it streaked back into the atmosphere. Many hundreds of miles from Cape Canaveral, airplanes vectored to the impact area and soon picked up the capsule's recovery signals. Two destroyers raced to the area

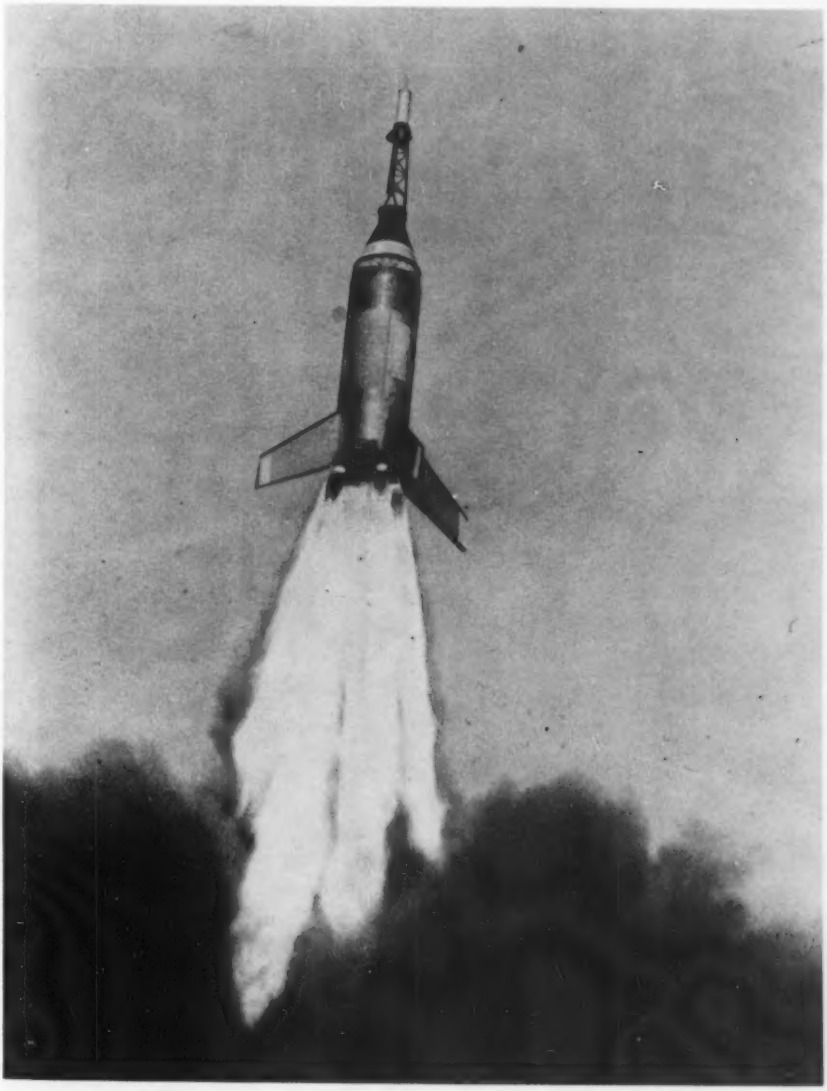


FIGURE 73.—Little Joe Launching.

FIGURE 74.—Retrieval of Capsule After Little Joe Flight.

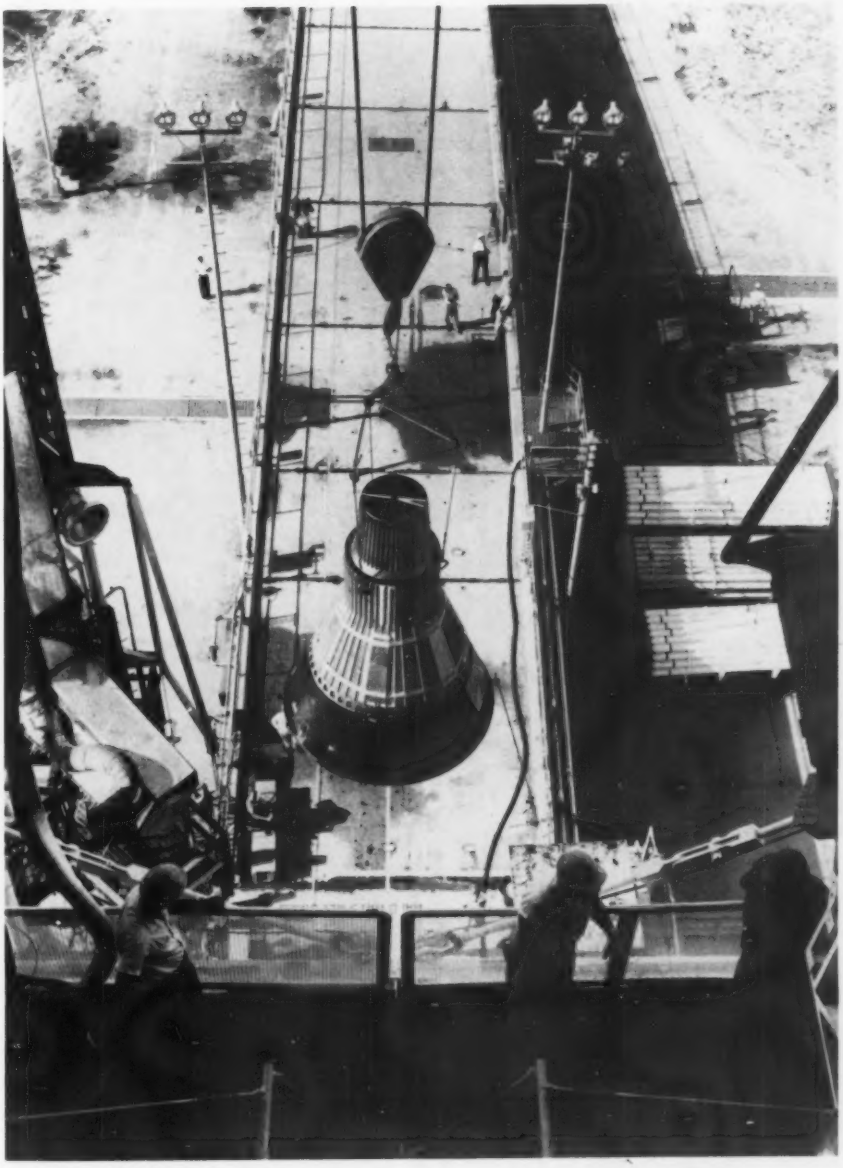


FIGURE 75.—Big Joe Capsule Being Lifted to Top of Gantry.

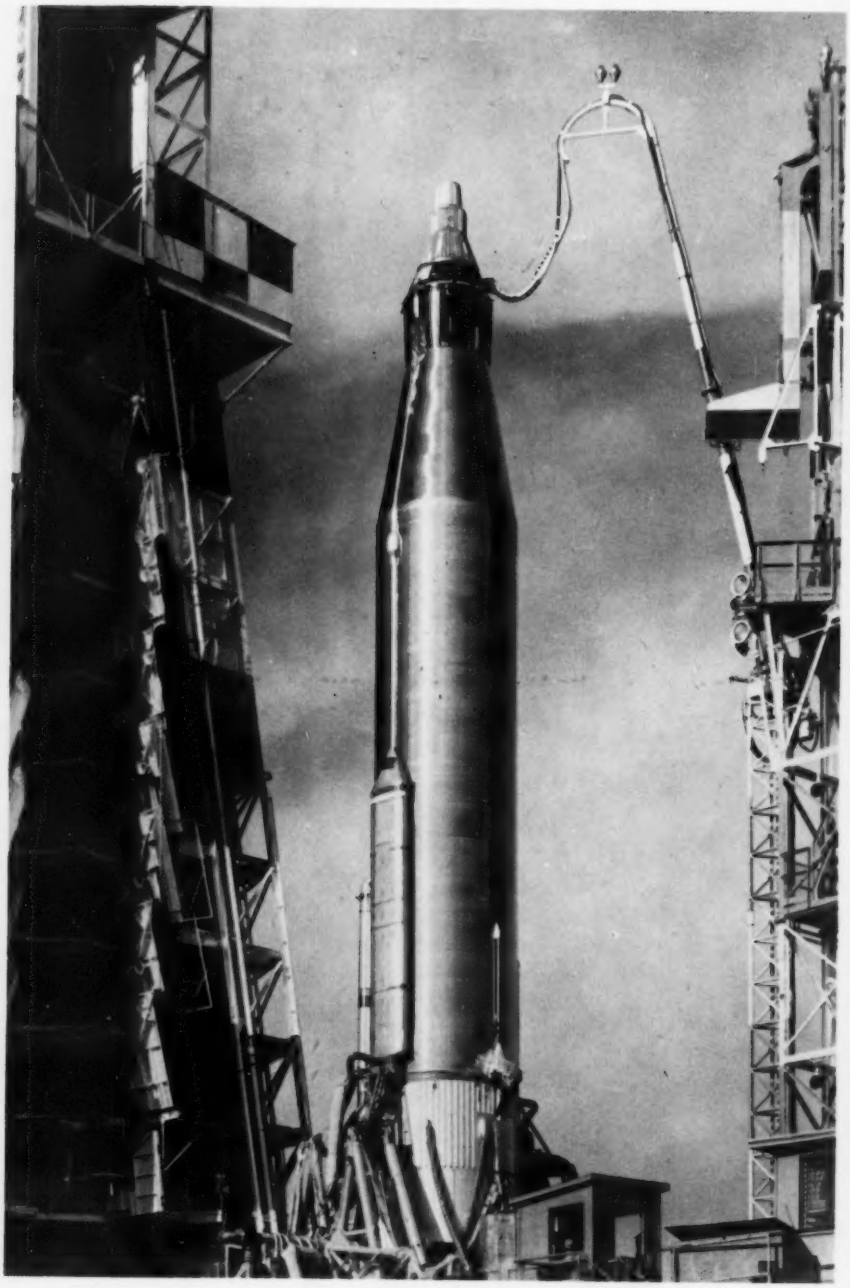


FIGURE 76.—Big Joe Prior to Launch.

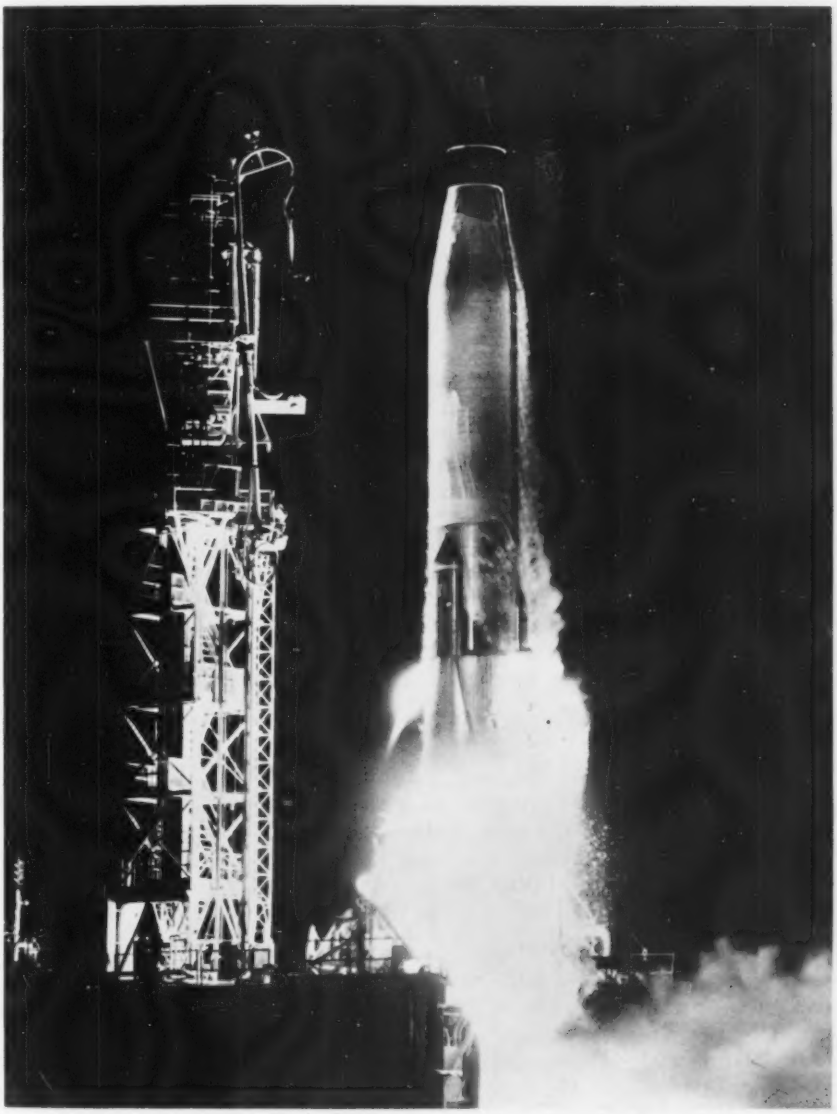


FIGURE 77.—Launching of Big Joe.

and sighted the capsule about 8 hours after launch. Figure 78 shows the recovered capsule abroad the destroyer *Strong* prior to its return for a detailed inspection and for analysis of recorded data. It had survived its reentry in excellent condition.

The recovered Big Joe capsule represents a major milestone in Project Mercury, in that it positively demonstrated the validity of the Mercury design concept.

MERCURY CAPSULE PRODUCTION

In January 1959 the McDonnell Aircraft Corp. was selected as a prime contractor to design and construct the Mercury capsules. The selection was based on an industry-wide competition. In the course of this competition, 12 firms submitted proposals based on NASA specifications for the capsule. After a thorough evaluation of these proposals a contract was awarded to McDonnell.

Mockup inspection

An engineering mockup of the capsule was completed by McDonnell in March of 1959. The mockup was complete in every detail including the escape tower and rocket, the antenna housing, the parachute container, the capsule proper, and the adapter ring that connects the capsule to its booster. The mockup also included cockpit equipment and control layouts. Engineers and officials from NASA met with contractor personnel to assure that specifications governing the capsule design and the installation of equipment and components were complied with. After the mockup inspection had been completed, an official mockup board, consisting of NASA officials and military and aeromedical advisers, made final recommendations. A picture of the capsule mockup without the escape tower is shown in figure 79.

Capsule construction

The construction of the capsule's pressure vessel is illustrated in figure 80. This vessel consists of a smooth inner skin and a beaded outer skin. Each of these is made of titanium, and is one-hundredth of an inch thick. After the two skins are welded together, the stringers, windows, and door frames and bulkhead rings are installed. An additional skin will be attached to stringers.

Components and subsystems

Many of the component parts of the capsule are made by subcontractors under McDonnell supervision. The following are the major subcontractors' items: automatic stabilization and control system, Minneapolis-Honeywell Regulator Co.; environmental control system, AiResearch Manufacturing Co.; hydrogen peroxide control system, Bell Aircraft Corp.; backup hydrogen peroxide control jets, Food Machinery & Chemical Corp.; batteries, the Eagle-Picher Co.; communication system, Collins Radio Co.; ablation heat shield, Cincinnati Testing & Research Laboratories; beryllium heat shield, the Brush Beryllium Co.; parachute landing system, Radioplane Division of Northrop Aircraft Corp.; escape rocket, Grand Central Rocket Co., Inc.; retrograde and posigrade rockets, Thiokol Chemical Corp.; navigation periscope, the Perkin-Elmer Corp.; horizon scanners, Barnes Engineering Co.

FIGURE 78.—Recovered Big Joe Capsule After Flight From Cape Canaveral.

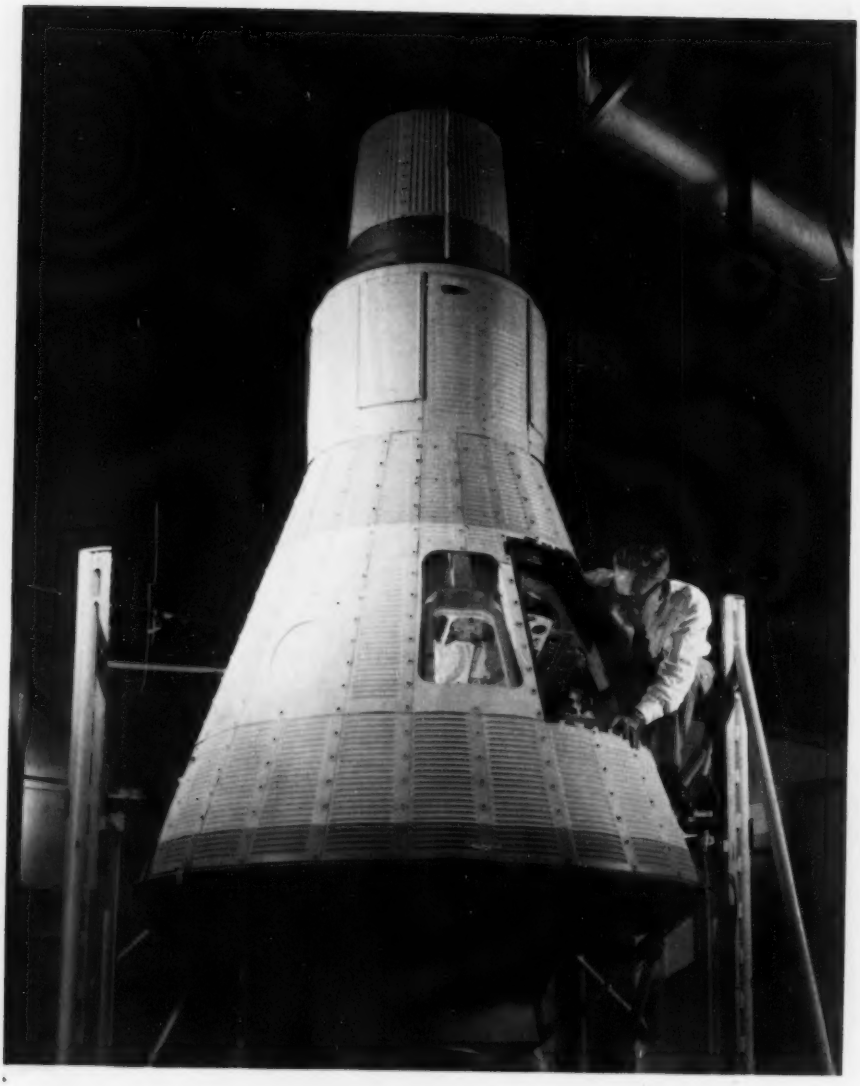


FIGURE 79.—Mercury Capsule Mockup.

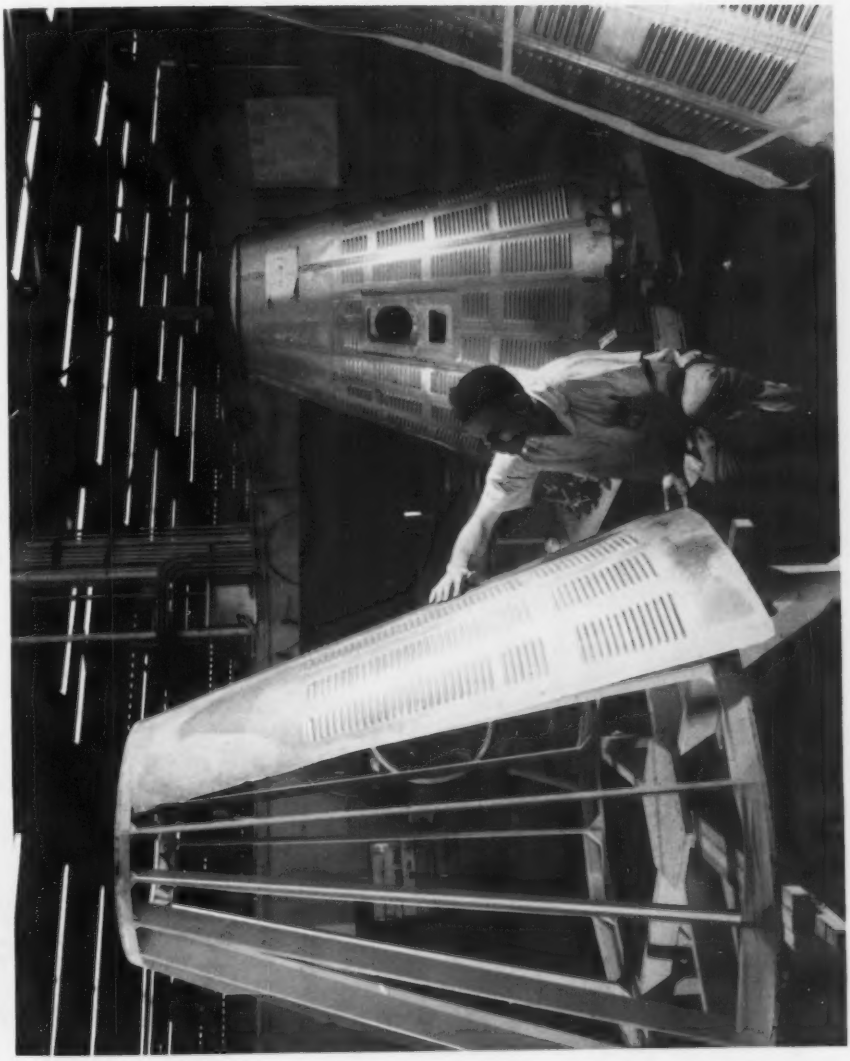


FIGURE 80.—Construction of Capsule's Pressure Vessel.

Capsule assembly

Final fabrication of a number of capsules is well under way. Figure 81 illustrates a scene on the production line at the McDonnell plant, where several capsules are in various stages of construction. On this line the pressure vessel is fitted with the upper and lower pressure bulkheads; a large number of brackets and fixtures are installed for the support of the capsule systems, the wiring and the reaction control fuel lines. After capsule fabrication is completed, the various subsystems are installed. The assembled capsule is then subjected to intensive environmental testing. The entire system must be able to withstand extreme heat and cold, high pressure and vacuum, vibration and noise, and high accelerations. All of these tests are performed on the ground before the capsule is certified as being ready for flight.

The compressed time-phasing of the project between inception and scheduled flight has required that research, development, design, and fabrication be undertaken simultaneously. Inevitably under these conditions experience has required that modifications to design, arrangement, and structure be made during the conduct of the program. To date, a large number of capsule changes have been made as a result of potential trouble areas that have been uncovered in the research and development program; further changes were incorporated to insure the safety of the pilot.

A total of 24 capsules will be required for the various phases of the flight program. Early in 1960 a number of capsules were nearing completion.

QUALIFICATION FLIGHT TESTS

Immediately after delivery of the first capsules, a qualification flight test program will be initiated. In this program the production capsules will be flown on successively more difficult missions, culminating with the design mission of orbital flight.

In the first tests, to be carried out in the first half of calendar year 1960, the escape sequence will be tested in a simulated off-the-pad abort flight and in another Little Joe flight.

Redstone ballistic flights

Starting in about the middle of this year, an important series of ballistic flights will be initiated, using the Redstone booster.

As illustrated in figure 82, the Redstone will carry the capsule to an altitude of 125 miles, and to a distance of 200 miles from Cape Canaveral. The flight will last 16½ minutes. During that time, the capsule will be accelerated to a speed of 4,000 miles per hour and will withstand forces as high as 6½ g. during exit and 11 g. during reentry. A weightless time of 5½ minutes will be sustained.

Initially, the Redstone-boosted capsules will contain only instruments. Later on, a capsule containing a chimpanzee will be flown along the same trajectory, and, when all systems are sufficiently reliable, manned ballistic flights will be made. In these flights, man will be subjected to more than five times the period of weightlessness than has heretofore been possible. The experience gained by the astronaut in the operation of the capsule in these relatively short flights will be exceedingly valuable as part of the training program for the later manned orbital flights.

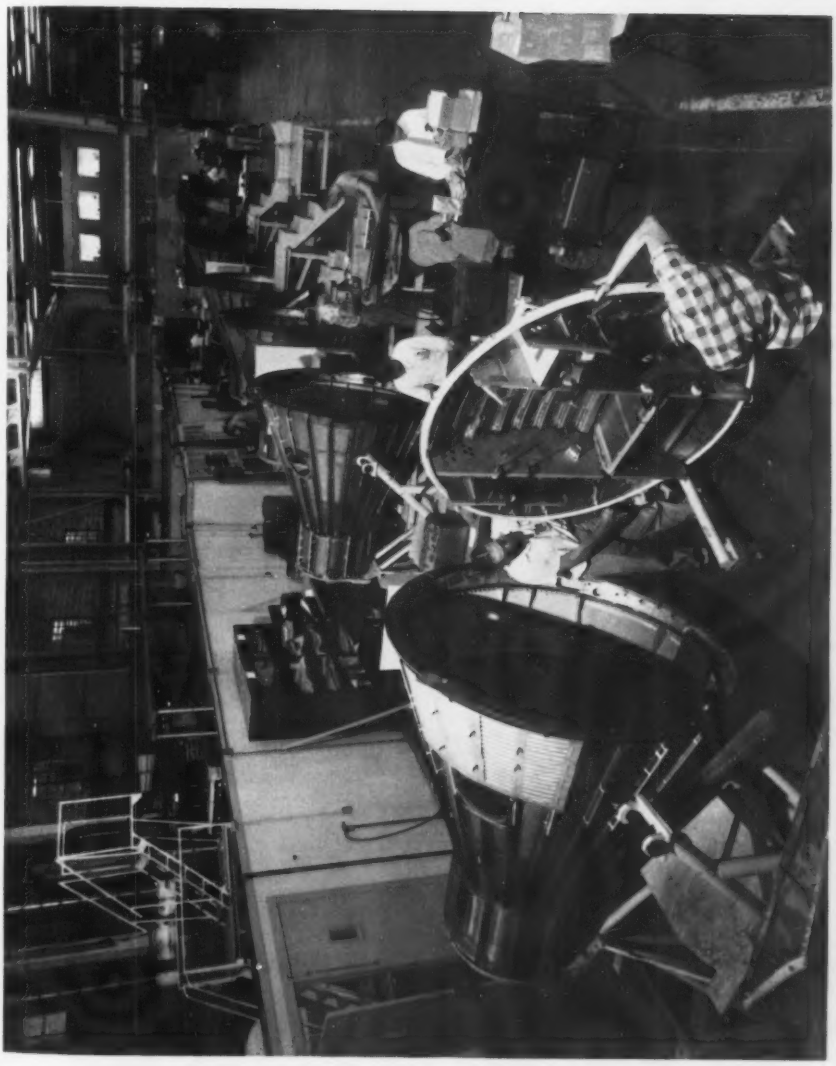


FIGURE 81.—Capsule Production Line at McDonnell.

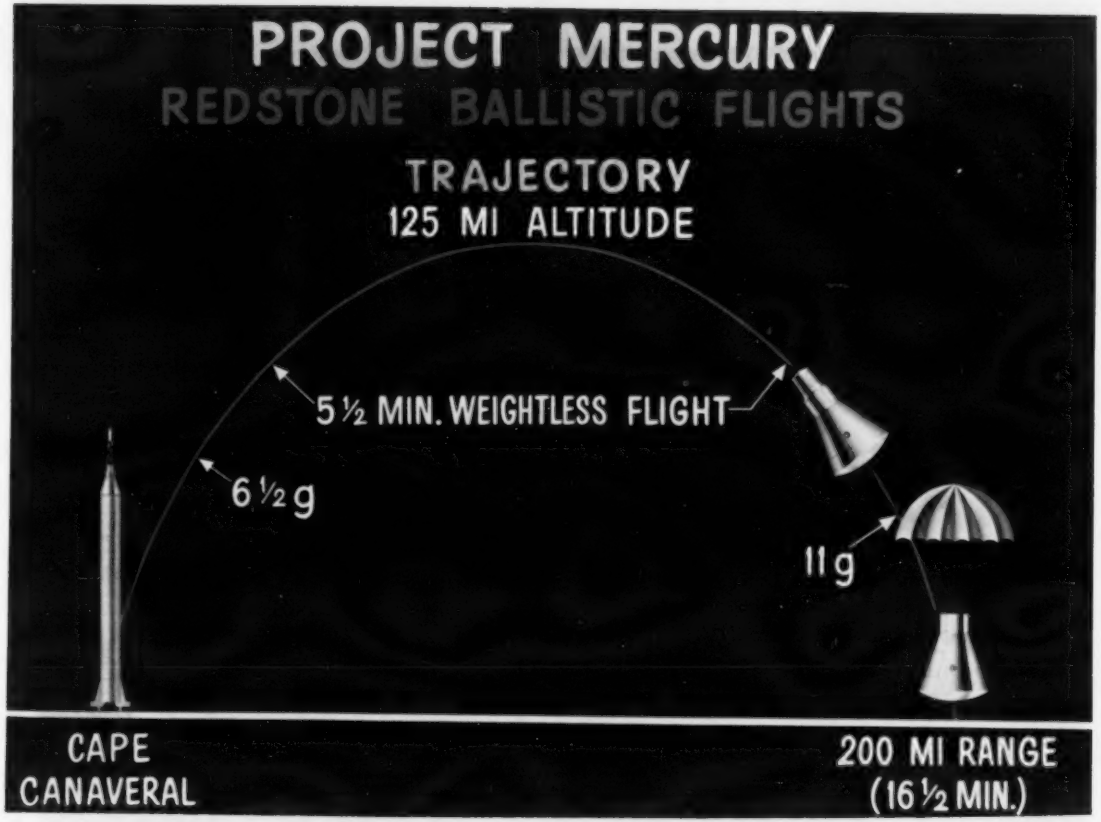


FIGURE 82.—Redstone Ballistic Flights.

Atlas ballistic flights

Capsule qualification at speeds higher than those possible with the Redstone will be carried out with the Atlas. As illustrated in figure 83, the Atlas will launch the Mercury capsule along a series of ballistic trajectories before it is employed in the orbital mission. All of the Atlas ballistic flights will be unmanned.

One type of trajectory will give the worst possible reentry conditions that could be attained in an aborted orbital mission. In this flight, the capsule will plunge steeply back into the atmosphere after reaching an altitude of 140 miles. A peak deceleration of 19 g will be encountered during reentry.

Another type of Atlas trajectory will be shaped to duplicate exactly the velocity, altitude, and angle of orbital reentry without actually going into a satellite orbit. The primary objectives of this flight will be to qualify the capsule and its heat protection under actual reentry conditions, and to determine the stability characteristics of the capsule and the functioning of the reaction control system.

In the third type of ballistic flight the capsule will actually be inserted into orbit but will immediately be turned around and a reentry will be executed. During this flight an altitude of 120 miles will be reached and a range of 4,000 miles will be attained. In addition to providing complete qualification of the capsule and all of its systems, this flight will give the operations personnel the necessary training and experience needed before orbital flights can be attempted. This will include experience in ground handling, launch, and orbital insertion, the retrograde maneuver, tracking and computing, and search-and-recovery operations.

ORBITAL FLIGHTS

Flight conditions

After completion of the ballistic flight tests, the capsule and its launch vehicle will be ready for the first orbital flight. The altitude of the orbit will be 120 miles, and the speed 17,500 miles per hour. Each orbit will last 90 minutes. It is planned to keep the capsule aloft for three complete earth orbits, or 4½ hours.

The first time the capsule is sent into orbit, it will contain only instruments so that the functioning of all the equipment can be checked. Later on, a capsule containing an animal will be flown to check the life-support system, the biological instrumentation on board, and to determine the physiological effects of long-term exposure to weightless flight.

Only after successful instrumented and animal flights have been completed will the first manned flight take place.

Operational considerations

Some of the operational procedures to be followed in the orbital flights are shown in figure 84. The capsule will be launched from Cape Canaveral in a direction toward Bermuda. The shaded areas on the map illustrate the planned recovery areas. Ships and aircraft will be deployed in all of these areas in order to effect the recovery at the earliest possible time.

The ships deployed along the initial flight path between Florida and the Canary Islands will be used to retrieve the capsule in case of

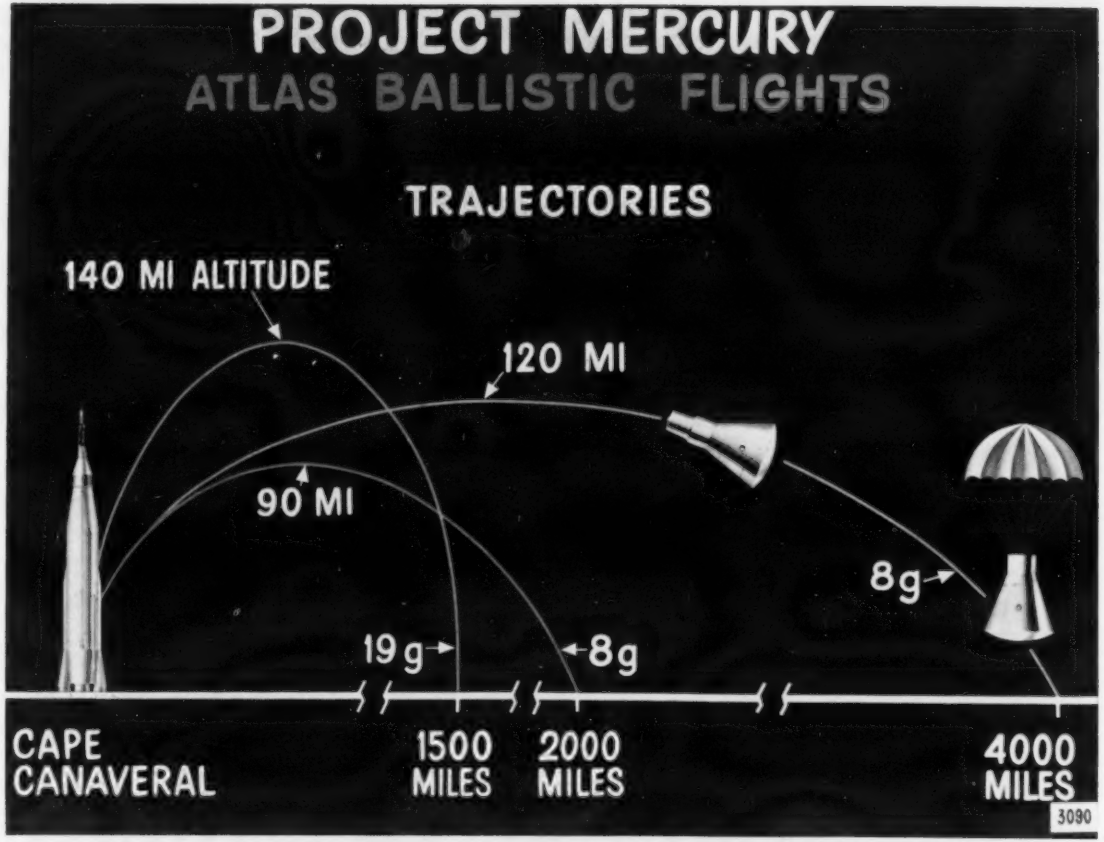


FIGURE 83.—Atlas Ballistic Flights.

PROJECT MERCURY

FIGURE 83.—Atlas Ballistic Flights.

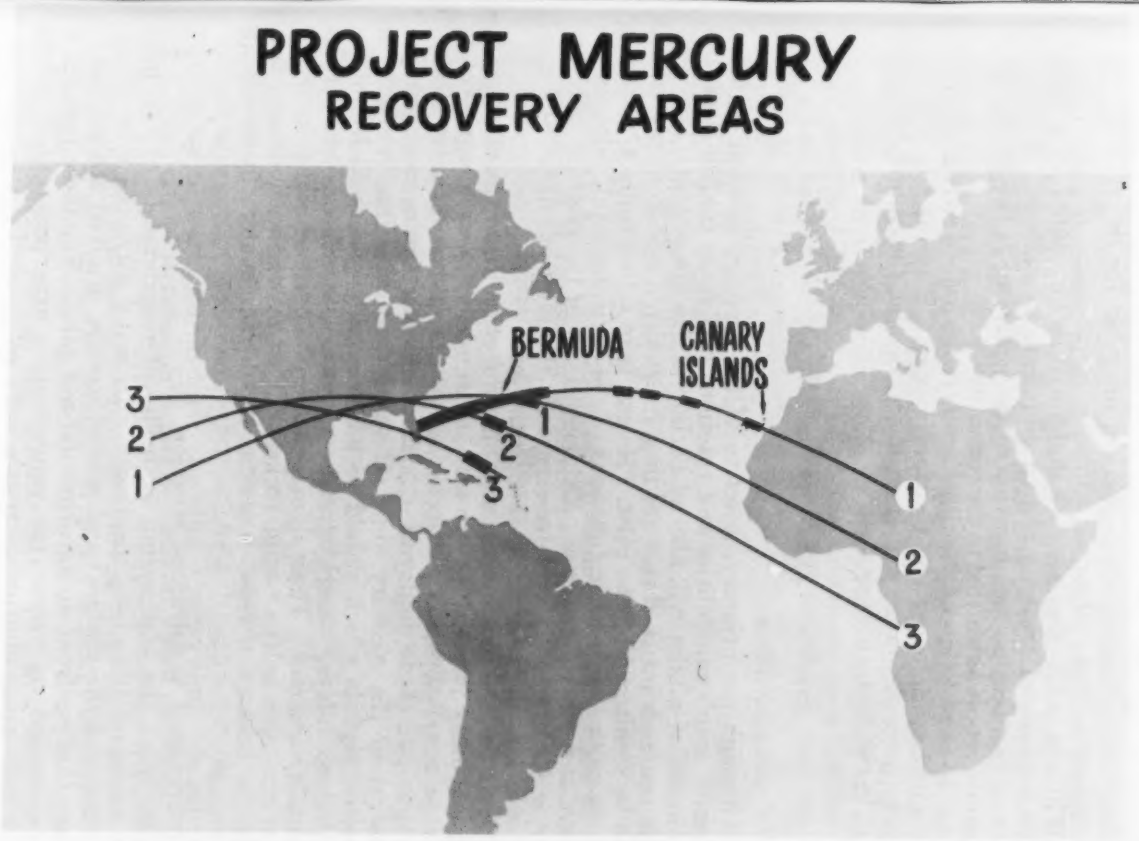


FIGURE 84.—Recovery Areas.

an aborted flight. If there are indications during the early stages of flight that for some reason it would be impossible to complete one orbit, then immediate action to terminate the flight will be taken. The capsule would then be brought down within one of five predetermined landing areas in the Atlantic Ocean.

Emergency landing areas also are provided for return after completion of the first and second orbits.

While in orbit, the capsule's flight will be monitored by a worldwide network of tracking and communications stations. A description of the location and function of these stations is the subject of a separate report submitted to the committee.

At the completion of the third orbit, the capsule's retrograde rockets will be fired near the California coast. The capsule will then slowly descend toward the atmosphere, reenter the atmosphere, and land in the Atlantic Ocean.

ASTRONAUT SELECTION AND TRAINING

Pilot responsibilities

Although the primary objective of the Mercury mission is to determine man's capabilities and reactions in a space environment, the inclusion of a pilot will also add reliability to the system. The capsule contains many direct reading instruments and controls which can be monitored by the pilot. He can take action to back up many of the critical automatic functions of the environmental, communications, and control systems. Although much of the systems' monitoring is done remotely by telemetry, only the pilot has direct and continuous knowledge of the systems' behavior.

Probably the most important pilot function from the standpoint of reliability is his ability to monitor and back up such sequences as escape tower separation, capsule separation, retrofire, retrojettison, drogue parachute deployment, main parachute deployment, and actuation of the recovery aids. Most of these functions result from electric signals which should be automatically generated by microswitches, relays, timers, pressure switches, accelerometers, or by ground command. These signals then ignite pyrotechnic squibs which fire explosive bolts or solid rockets. Past experience indicates that manual backup of these functions should add materially to overall reliability.

Criteria used in astronaut selection

Many of the engineering or technical requirements of the pilot or astronaut have been mentioned. In many ways the type of decisions and the physical and mental stresses involved are similar to those that confront an experimental-test pilot. For these reasons, it was decided to restrict the volunteers to experimental-test pilots. The following additional criteria were established:

1. Flying experience, 1,500 hours;
2. Graduation from a military test pilot school;
3. Bachelor degree or equivalent in engineering or science;
4. Under age 40;
5. Height, 5 feet 11 inches, or less. (Height was restricted because the diameter of the Mercury capsule limits pilot's size to 5 feet 11 inches in the support couch.)

Selection procedure

Personnel records were screened based on the above criteria. Approximately 100 men met these qualifications. In February 1959, two-thirds of this group were briefed on Project Mercury and a high percentage volunteered. Those who volunteered were interviewed and were given advanced aptitude tests. Based on this additional information, 32 men were chosen to proceed to the Lovelace Clinic for a thorough medical examination and then to Wright Air Development Center for a week of physical stress tests. During the stress tests, the candidates experienced accelerations up to 12 g, pressure altitude of 100,000 feet in a partial pressure suit, and high temperature levels.

However, the results of the previously mentioned tests were used only in support of the selection procedures; the final selections were based primarily on past performance and engineering capabilities in relation to the specific needs of Project Mercury. During the first week in April 1959, seven of the volunteers were notified that they had been chosen as Mercury pilots. These seven men are—

M. Scott Carpenter.
L. Gordon Cooper, Jr.
John H. Glenn, Jr.
Virgil I. Grissom.
Walter M. Schirra, Jr.
Alan B. Shepard, Jr.
Donald K. Slayton.

Figure 85 is a picture of the seven astronauts. Biographical sketches are attached at the end of this section.

Engineering activities and familiarization program

The Mercury pilots have been assigned to the following subsystems or specialty areas:

1. Communications and navigation, Carpenter;
2. Control system, Grissom;
3. Cockpit layout, Glenn;
4. Life-support system, Schirra;
5. Tracking and recovery, Shepard;
6. Redstone booster, Cooper;
7. Atlas booster, Slayton.

It is the responsibility of each man to determine if, within his particular area, the system is compatible with manned operation. In addition to work within their specialty assignments, the pilots, as a group, attend lectures on rocket propulsion, space mechanics, gyroscope theory, stable platforms, space navigation, communications, meteorology, astronomy, and physics of the upper atmosphere. The pilots also receive status briefings from the NASA Mercury Project engineers.

An important part of the familiarization program involves visits to the various contractor and service facilities. Group visits have been made to McDonnell, Convair, Rocketdyne, ABMA, BMD, and Cape Canaveral. The pilots visit individually the subcontractors within their own specialty areas. During these visits they are briefed on the Mercury systems and on advanced programs which are under study and development.

FIGURE 85.—Mercury Astronauts Carpenter, Slayton, Cooper, Shepard, Glenn, Grissom, Schirra.

Flight simulators and training facilities

In order to familiarize the pilot with the capsule environment and to provide procedural training, several static and dynamic simulators have been scheduled. They are:

(*a*) *Analog computer.*—This computer, in conjunction with a fixed-base simulator, gives the pilot practice in controlling the vehicle with the manual control system. A pilot instrument panel contains the actual capsule flight instruments which are driven by an analog computer. Six-degree-of-freedom equations of motion are programed into the computer. The pilots practice manual control during simulated orbit, retrofire, and reentry.

(*b*) *Flight simulator.*—This simulator is similar to the analog computer but includes an instructor's console.

(*c*) *Procedures trainers.*—The procedures trainer is a mockup of the interior of the actual capsule and, in conjunction with the flight simulator, will provide a closed loop simulation in which the pilot can become familiar with all procedural aspects of normal and emergency missions. A second procedural trainer will be used at Cape Canaveral to provide additional training in range, network, and launching procedures.

(*d*) *ACEL environmental system trainer.*—A complete life-support system will be placed in the decompression chamber at the Navy Air Crew Equipment Laboratory in Philadelphia. This trainer will serve the dual purpose of qualifying the environmental control system and familiarizing the pilots with the system's characteristics.

(*e*) *Human centrifuge facilities.*—The human centrifuge facilities at Wright Air Development Center and at the Johnsville Navy Development Center provide familiarization with high acceleration and also give practice in closed loop control of the capsule during simulated reentry (figs. 86 and 87).

(*f*) *Air-bearing attitude simulator.*—A support couch mounted on a low-friction air-bearing is used to familiarize the pilots with the orbital dynamics of the capsule under influence of the reaction-control jets. This simulator is shown in figure 88.

(*g*) *Gimballed attitude simulator.*—This simulator, shown in figure 89, is located in the altitude wind tunnel at the Lewis Research Center; it possesses complete angular freedom in pitch, yaw, and roll and provides practice in controlling a capsule with severe angular rotation.

(*h*) *Capsule egress trainer.*—A special egress capsule, shown in figure 90, has been fabricated and will be placed in various sea conditions for pilot egress practice.

(*i*) *Zero-g flights.*—Flights in specially equipped C–131 and F–100F aircraft provided weightless flight for periods of 15 seconds and 1 minute, respectively. Three astronauts during weightless flight in the C–131 are shown in figure 91.

(*j*) *Zero-g water tank.*—A water tank mounted on bearings will be used to determine pilot disorientation under partially simulated zero-g conditions.

(*k*) *Planetarium.*—The pilots were given a brief course in star identification at the Morehead Planetarium. Since the stars will be visible at all times from the orbiting capsule, star position and star tracks will be valuable aids for navigation and attitude reference.

FIGURE 86.—Human Centrifuge at Johnsville Navy Development Center.

FIGURE 87.—Astronaut Grissom During a High-G Run on Centrifuge.

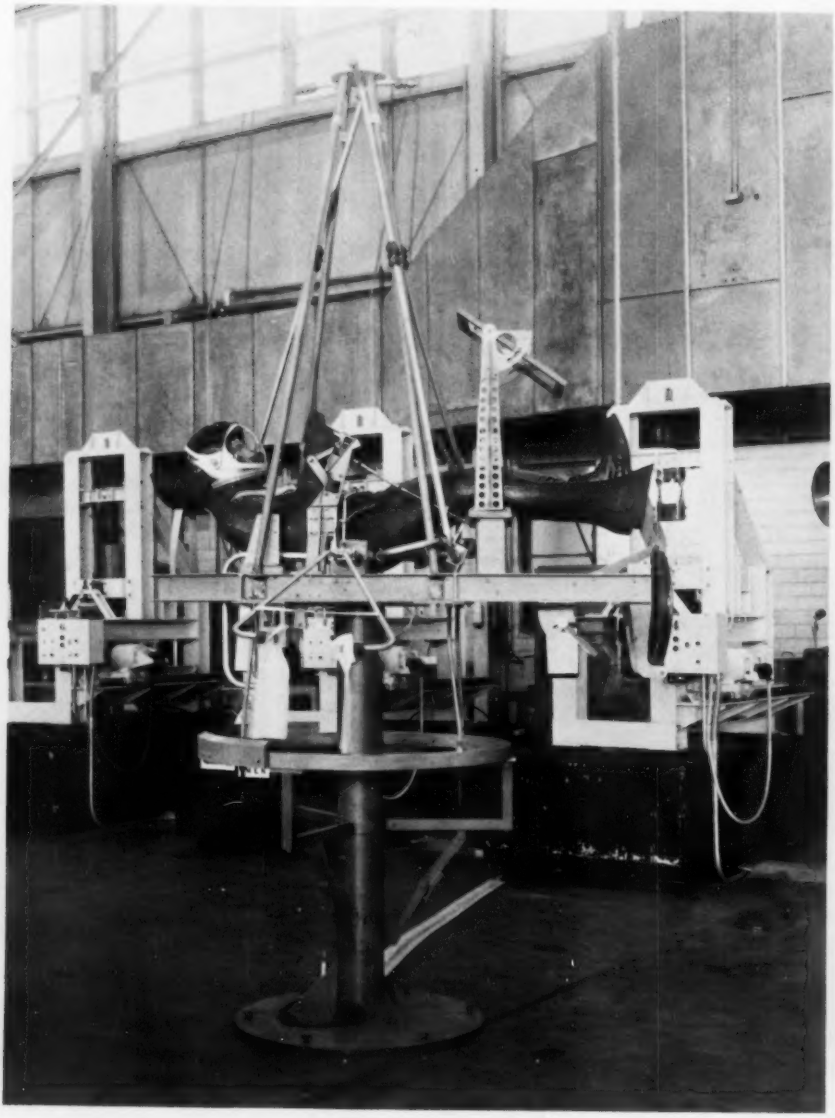


FIGURE 88.—Air-Bearing Attitude Simulator.

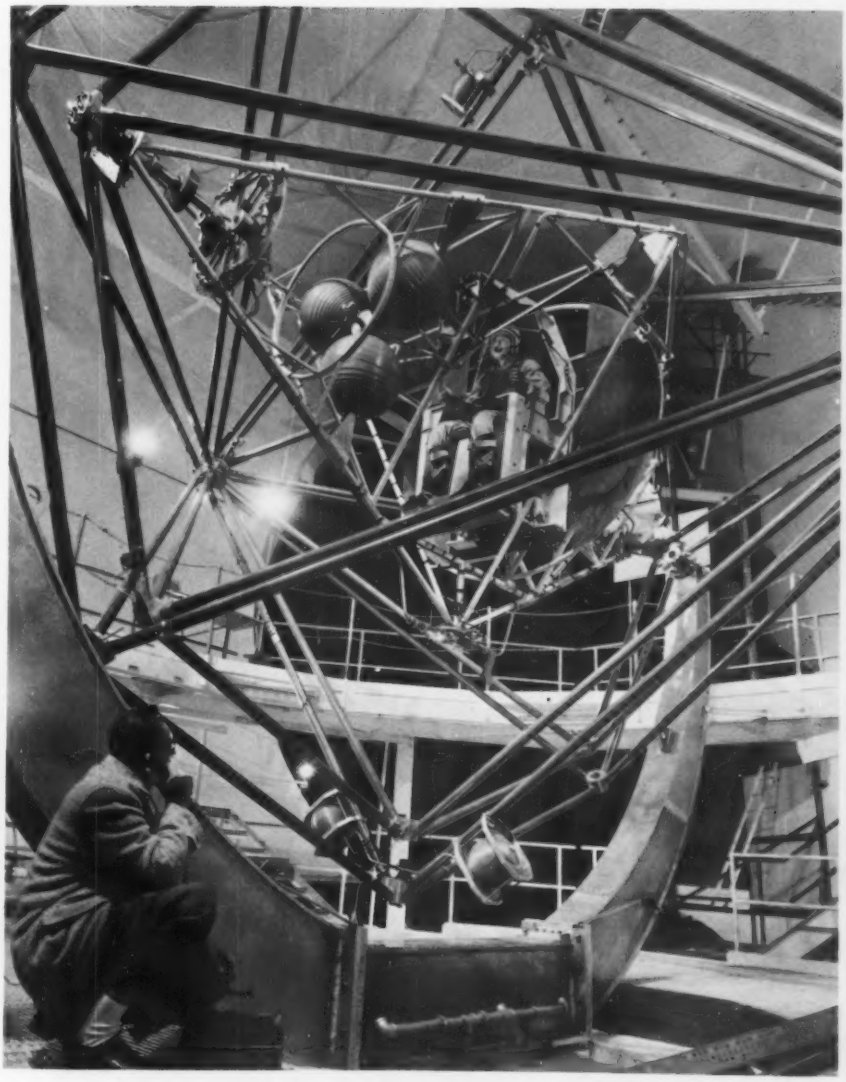


FIGURE 89.—Gimballed Attitude Simulator.

FIGURE 90.—Astronaut Schirra After Egress From Capsule in Simulated High Sea Condition.

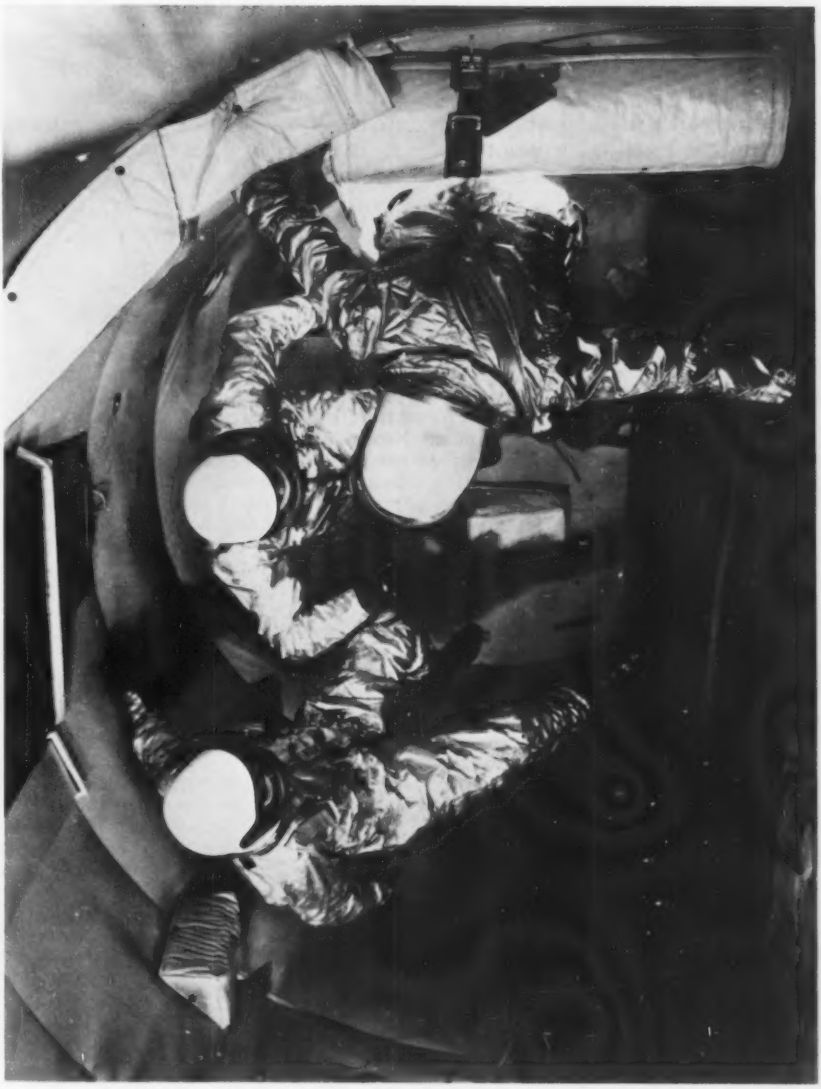


FIGURE 91.—Three Astronauts in Weightless Flight.

(*l*) *Pressure suits.*—The Mercury pressure suits, shown in figure 92, are worn during training exercises in many of the previously mentioned facilities. The pressure suit reduces pilot mobility; consequently it is necessary to determine that control manipulation is compatible with the pressure suit.

Operational experience

Prior to the manned Redstone and Atlas flights, the pilots will be familiar with all aspects of the capsule systems and mission details. During each orbital mission, four or five of the pilots will be spotted at the tracking stations and will act as capsule communicators.

Astronaut biographies

The biographies of the astronauts are as follows:

MALCOLM SCOTT CARPENTER, PROJECT MERCURY ASTRONAUT

Malcolm S. Carpenter, a lieutenant in the U.S. Navy, was born May 1, 1925, in Boulder, Colo. His mother is living in Boulder at 5335 Broadway. Carpenter's father, a retired chemist, lives in Palmer Lake, Colo. His wife is the former Rene Louise Price, whose parents, Mr. and Mrs. Lyle S. Price, live at 963 Ninth Street, Boulder. The Carpenters have four children: Mark Scott, 10; Robyn Jay, 8; Kristen Elaine, 4; and Candace Noxon, 3. Carpenter is 5 feet 10½ inches tall, weighs 160 pounds, and has green eyes and brown hair.

After receiving his early education through high school in Boulder, Carpenter entered Colorado College in 1943 to participate in the V–5 flight training program sponsored by the U.S. Navy. After a year there, he spent 6 months in training at St. Mary's preflight school, Moraga, Calif., and 4 months in primary flight training at Ottumwa, Iowa. When the V–5 program ended at the close of World War II, Carpenter entered the University of Colorado to major in aeronautical engineering. He received a degree there in 1949.

Following his graduation, Carpenter joined the Navy and received flight training from November 1949, to April 1951, at Pensacola, Fla., and Corpus Christi, Tex. He spent 3 months in the Fleet Airborne Electronics Training School, San Diego, Calif., and until October 1951, in a Lockheed P2V transitional training unit at Whidbey Island, Wash.

In November 1951, he was assigned to Patrol Squadron 6 based at Barbers Point, Hawaii. During the Korean conflict, he was engaged with Patrol Squadron 6 in antisubmarine patrol, shipping surveillance and aerial mining activities in the Yellow Sea, South China Sea, and the Formosa Straits. In 1954 he entered the Navy Test Pilot School at the Naval Air Test Center, Patuxent River, Md., and after completion of his training, was assigned to the electronics test division of the NATC. In this assignment Carpenter conducted flight test projects with the A3D, F11F, and F9F and assisted in other flight test programs. He then attended the Navy's General Line School at Monterey, Calif., for 10 months and the Naval Air Intelligence School, Washington, D.C., for a further 8 months. In August 1958, he was assigned to the U.S.S. *Hornet*, antisubmarine aircraft carrier, as air intelligence officer. He has accumulated more than 2,800 flying hours, including 300 in jet aircraft.

His hobbies include skin diving, archery and water skiing.

LEROY GORDON COOPER, JR., PROJECT MERCURY ASTRONAUT

Leroy G. Cooper, Jr., a captain in the U.S. Air Force, was born March 6, 1927, in Shawnee, Okla. He is 5 feet, 9½ inches tall and weighs 150 pounds. The 33-year-old astronaut has blue eyes and brown hair. He considers as his hometown Carbondale, Colo., where his parents, Col. and Mrs. Leroy G. Cooper, have a ranch. Colonel Cooper is retired from the Air Force. Captain Cooper's wife is the former Trudy Olson of Seattle, Wash. The couple have two daughters, Camala K., 11, and Janita L., 10.

Cooper attended primary and secondary schools in Shawnee, and he attended the University of Hawaii 3 years. He received a degree in aeronautical engi-

FIGURE 92.—Astronaut Slayton in Mercury Pressure Suit.

neering through the Air Force Institute of Technology at Wright-Patterson Air Force Base, Ohio, in August 1956.

Cooper entered the Marine Corps in 1945 after his graduation from high school. He attended the Naval Academy Preparatory School and was a member of the Presidential Honor Guard in Washington immediately before his discharge in August 1946. While at the University of Hawaii, he received a commission in the Army. He transferred this commission to the Air Force and was recalled by that service for extended active duty in 1949 for flight training. After his training, he was assigned to the 86th Fighter Bomber Group in Munich, Germany, as an F–84, and later, an F–86 pilot. After his graduation from AFIT, he was assigned to the Air Force Experimental Flight Test School at Edwards Air Force Base, Calif. He was graduated from this school in April 1957, and was assigned duty in the Performance Engineering Branch of the Flight Test Divison at Edwards. He conducted flight test on experimental fighter aircraft. Cooper has 2,300 flying hours, including 1,400 in jets.

His hobbies are photography, riding, hunting, and fishing.

JOHN HERSCHEL GLENN, JR., PROJECT MERCURY ASTRONAUT

John H. Glenn, Jr., a lieutenant colonel in the U.S. Marine Corps, was born July 18, 1921, in Cambridge, Ohio. He considers New Concord, Ohio, his permanent home. He attended primary and high schools in New Concord, and Muskingum College. His parents are Mr. and Mrs. John H. Glenn. The elder Glenn is a retired operator of a plumbing and heating business. Mrs. Glenn is the former Anna Margaret Castor, daughter of Dr. and Mrs. H. W. Castor. The elder Glenns and Castors all live on Bloomfield Road in New Concord. The Glenns have two children: John David, 14, and Carolyn Ann, 13. Glenn also has a sister, Mrs. Jean Pinkston, of Cambridge. He is 5 feet 10½ inches tall, weighs 180 pounds and has green eyes and red hair.

Glenn entered the naval aviation cadet program in March 1942. He was graduated and commissioned in the Marine Corps a year later. After advanced training, he joined Marine Fighter Squadron 155 and spent a year flying F4U fighters in the Marshall Islands. During his World War II service, he flew 59 combat missions. After the war, he was a member of Fighter Squadron 218 on North China patrol and had duty in Guam. From June 1948, to December 1950, he was an instructor in advance training at Corpus Christi, Tex. Glenn then attended Amphibious Warfare School at Quantico, Va. In Korea, he flew 63 missions with Marine Fighter Squadron 311, and 27 while an exchange pilot with the Air Force. In the last 9 days of fighting in Korea, he downed three Mig's in combat along the Yalu River. After Korea, Glenn attended test pilot school at the Naval Air Test Center, Patuxent River, Md. After graduation, he was project officer on a number of aircraft, including the F8U, F8U–1 and F8U–P. Since November 1956, he has been assigned to the Fighter Design Branch of the Navy Bureau of Aeronautics in Washington.

Glenn has been awarded the Distinguished Flying Cross on 5 occasions and he holds the Air Medal with 18 clusters for his service during World War II and Korea. In July 1957, while project officer of the F8U, he set a transcontinental speed record from Los Angeles to New York, spanning the country in 3 hours 23 minutes. He has more than 5,000 hours of flying time, including 1,500 hours in jet aircraft. Glenn has been attending the University of Maryland during his Washington assignment.

The Glenn family hobbies are boating and water skiing.

VIRGIL IVAN GRISSOM, PROJECT MERCURY ASTRONAUT

Virgil I. Grissom, a captain in the U.S. Air Force, was born April 3, 1926, in Mitchell, Ind. He is 5 feet 7 inches tall, weighs 155 pounds, and has brown eyes and brown hair. His parents, Mr. and Mrs. Dennis D. Grissom, live at 715 Baker Street, Mitchell. He has two brothers, Norman, of Mitchell, and Lowell, a sophomore at Indiana University, and a sister, Mrs. Joe Beavers, of Baltimore. Mrs. Grissom is the former Betty L. Moore. Her father, Claude Moore, lives in Mitchell. Her mother is deceased. The Grissoms have two sons, Scott, 10, and Mark, 6.

Grissom attended primary and high schools in Mitchell and was graduated from Purdue University with a degree in mechanical engineering in 1950. He first entered the Air Force in 1944 as an aviation cadet. He was discharged in November 1945. He returned to aviation cadet training after his graduation from Purdue, and he received his wings in March 1951. Grissom joined the 75th Fighter-Interceptor Squadron at Presque Isle, Maine, as an F–86 fighter pilot. He flew 100 combat missions in Korea in F–86's with the 334th Fighter-Interceptor Squadron. He left Korea in June 1952 and became a pilot instructor at Bryan, Tex. In August 1955, he went to the Air Force Institute of Technology at Wright-Patterson Air Force Base, Ohio, to study aeronautical engineering. In October 1956 he attended test pilot school at Edwards Air Force Base, Calif., and returned to Wright-Patterson AFB in May 1957, as a test pilot assigned to the Fighter Branch. He has flown more than 3,000 hours, over 2,000 in jets.

Grissom has been awarded the Distinguished Flying Cross and Air Medal with cluster.

His hobbies are hunting and fishing.

WALTER MARTY SCHIRRA, JR., PROJECT MERCURY ASTRONAUT

Walter M. Schirra (Shi-RAH), Jr., a lieutenant commander in the U.S. Navy, was born March 12, 1923, in Hackensack, N.J. The 37-year-old astronaut is 5 feet, 10 inches tall, weighs 185 pounds, and has brown hair and brown eyes. His parents, Mr. and Mrs. Walter M. Schirra, reside in Honolulu, Hawaii, where the elder Schirra is a civil engineer with the Air Force. The senior Schirra was a World War I ace in the Army Air Corps. After the war, he and his wife barnstormed throughout the Eastern United States in a light plane. The astronaut's wife is the former Josephine C. Fraser of Seattle, Wash. The couple has two children: Water III, 9, and Suzanne Karen, 2. Mrs. Schirra is the daughter of Mrs. James L. Holloway, wife of Admiral Holloway, who was commander in chief of the Northeastern Atlantic and Mediterranean area. Schirra also has a sister, Mrs. John H. Burhans, who lives in Patuxent River, Md.

Schirra attended primary and junior high schools in Oradell, N.J. He was graduated from Dwight Morrow High School, Englewood, N.J., in 1940, and attended Newark (N.J.) College of Engineering 1 year. He was graduated from the U.S. Naval Academy in 1945.

Schirra has had service on board the battle cruiser *Alaska*, the staff of the Seventh Fleet, flight training at Pensacola, in a Navy fighter squadron (71), and as an exchange pilot with the 154th U.S. Air Force Fighter Bomber Squadron. He went with this squadron to Korea where he flew 90 combat missions in F–84E aircraft. He downed one Mig and has one probable Mig. He took part in development of the Sidewinder missile at China Lake, Calif. He was project pilot for the F7U–3 Cutlass and instructor pilot for the Cutlass and FJ3 Fury. He flew F3H–2N Demons as operations officer of Fighter Squadron 124 on board the carrier *Lexington* in the Pacific. He then attended Naval air safety officer school at the University of Southern California, and test pilot training at the Naval Air Test Center, Patuxent, Md. His last assignment was at Patuxent in suitability development work on the F4H. He has 3,000 hours of flying time, 1,700 hours in jets.

He has been awarded the Distinguished Flying Cross and two Air Medals for his Korean service.

ALAN BARTLETT SHEPARD, JR., PROJECT MERCURY ASTRONAUT

Alan B. Shepard, Jr., a lieutenant commander in the U.S. Navy, was born November 18, 1923, in East Derry, N.H. The 36-year-old astronaut is 5 feet, 11 inches tall, weighs 160 pounds and has blue eyes and brown hair. His parents, Col. and Mrs. Alan B. Shepard, live in East Derry where the elder Shepard, a retired Army of the United States officer, is an insurance broker. Shepard is married to the former Louise Brewer of Kennett Square, Pa. The couple has two daughters, Juliana, 9, and Laura, 3. Shepard's sister, Mrs. Pauline S. Sherman, resides in Montclair, N.J.

Shepard attended primary school in East Derry and was graduated from Pinkerton School, Derry, N.H., in 1940. He studied 1 year at Admiral Farragut Academy, Toms River, N.J., and then entered the Naval Academy, Annapolis.

He was graduated from Annapolis in 1944. He was graduated from the Naval War College, Newport, R.I., in 1958.

The astronaut saw service on the destroyer *Cosgrove*, in the Pacific during World War II. He then entered flying training at Corpus Christi, Tex., and Pensacola, Fla. He received his wings in March 1947. Subsequent service was in Fighter Squadron 42 at the Norfolk Naval Air Station and Jacksonville, Fla. He also spent several tours in the Mediterranean. Shepard went to test pilot school at Patuxent River, Md., and served two tours in flight test there. During this service, he took part in high altitude tests to obtain data on light at different altitudes and in a variety of air masses over the North American continent. He also took part in experiments in test and development of the Navy's inflight refueling system; carrier suitability trials of the F2H3 Banshee, and Navy trials of the first angled carrier deck. Between his flight test tours at Patuxent, Shepard was assigned to Fighter Squadron 193 at Moffet Field, Calif., a night fighter unit flying Banshee jets. He was operations officer of this squadron and made two tours with it to the Western Pacific on board the carrier *Oriskany*. He has been engaged in the test of the F3H Demon, the F8U Crusader, F4D Skyray and F11F Tigercat. He was project test pilot on the F5D Skylancer. The last 5 months at Patuxent were spent as in instructor in the test pilot school. After his graduation from the Naval War College, Shepard joined the staff of the commander in chief, Atlantic Fleet, as aircraft readiness officer. He has 3,600 hours of flying time, 1,700 in jets.

Shepard's hobbies are golf, ice skating, and water skiing.

DONALD KENT SLAYTON, PROJECT MERCURY ASTRONAUT

Donald K. Slayton, a captain in the U.S. Air Force, was born March 1, 1924, in Sparta, Wisc. The 36-year-old astronaut is 5 feet, 10½ inches tall, weighs 160 pounds, and has blue eyes and brown hair. His parents, Mr. and Mrs. Charles S. Slayton, live in Sparta. A brother, Howard, and sister, Mrs. Lyndahel Hagen, also live in Sparta. Slayton's immediate family also includes a brother Richard, of San Jose, Calif.; another brother, Elwood, and two sisters, Mrs. Milton Madsen and Mrs. Harold Schluenz, all of Madison. His wife is the former Marjorie Lunney, daughter of Mr. and Mrs. George Lunney of Los Angeles, Calif. The Slaytons have one son, Kent, 3.

Slayton attended primary and high schools in Sparta, graduating from Sparta High School in 1942. He entered the University of Minnesota in January 1947, and was graduated with a degree in aeronautical engineering in August 1949.

He entered the Air Force as an aviation cadet in 1942 and after instruction at Vernon, Tex., and Williams, Ariz., won his wings in April 1943. He flew 56 combat missions in B–25's in Europe with the 340th Bombardment Group (medium). In mid-1944, he returned to this country as a B–25 instructor pilot at Columbia, S.C., and then served with a unit checking out pilots in the A–26. He joined the 319th Bombardment Group (medium) and went to Okinawa in April 1945, where he flew seven combat missions over Japan. He was an instructor pilot in B–25 aircraft for about a year after the war. Following his graduation from the University of Minnesota, he was an aeronautical engineer with Boeing Aircraft Co. in Seattle, Wash., until recalled in early 1951 to active duty with the Air National Guard, in which he maintained membership during his student days at the University of Minnesota. On his recall, he was assigned to Minneapolis as maintenance flight test officer of an F–51 squadron. He then spent a year and one-half at 12th Air Force Headquarters as technical inspector, and a like period as fighter pilot and maintenance officer with the 36th Fighter Day Wing in Bitburg, Germany. He returned to the United States in June of 1955 and attended the Air Force Flight Test Pilot School at Edwards Air Force Base, Calif. Since January 1956, he has been an experimental test pilot at Edwards, where he has flown all jet-fighter-type aircraft built for the Air Force. His last assignment was chief of fighter section A. He has 3,400 flying hours, 2,000 in jets.

Slayton holds the Air Medal with cluster.

His hobbies are hunting, fishing, shooting, archery, photography, and skiing.

MERCURY SCHEDULE

Project Mercury is being carried out with the greatest possible speed and urgency; the flight program is tightly scheduled in order to meet all objectives at the earliest practicable date. The project has been awarded a DX priority rating, and thus carries a materiel priority equal to that of our ballistic missile program.

Progress to date

To date, more than 100 wind tunnel tests of the Mercury capsule have been performed, and 122 capsule models have been dropped from airplanes in the parachute development program. The escape system has been tested three times in simulated off-the-pad abort maneuvers, and four more escape system tests were performed in connection with four successful Little Joe flights. A small monkey was carried along on two of the Little Joe flights, in an attempt to gain further physiological data on the effects of space flight. And, as mentioned earlier, a single Atlas-launched capsule flight has been made. All flight tests to date employed "boilerplate" capsule models.

Flight schedule

The Mercury flight schedule is shown in figure 93. Shown on this schedule are the planned flights using the Little Joe, Redstone, and Atlas boosters.

It is planned to launch one more Little Joe, using a McDonnell production capsule, during 1960.

Redstone flights will start in the middle of calendar year 1960, and will continue for perhaps 1 year.

Atlas ballistic flights with McDonnell capsules are scheduled to begin during the summer of 1960. After a series of ballistic flights have been completed, instrumented capsules and capsules containing animals will be flown into a satellite orbit. Finally, the first manned orbital flight will take place.

ADVANCED REENTRY CONFIGURATIONS

Project Mercury is only the first step in our long-range program for the manned exploration of space. Long-range goals in our program include manned landings on the Moon, and still later, on the planets. Manned flight around the Moon will be a prerequisite for a lunar landing.

The Mercury capsule is not suitable as a return vehicle for a lunar mission. Instead, a capsule capable of reentering the atmosphere at higher speeds will be required. Our studies also indicate that a lunar-return vehicle must be capable of generating some aerodynamic lift in order to minimize the midcourse guidance requirements. Aerodynamic lift may also be used to control the landing point upon return from a satellite or space mission.

During fiscal year 1961, it is planned to initiate work in the area of advanced reentry configurations. Two major areas will be considered: The use of lift to facilitate reentry from space, and guidance and control methods for piloted space flight. Extensive analyses will be made and scale models of various configurations will be evaluated in wind tunnels. Flight simulators will be used to evaluate the pilot's capability to fly such vehicles.

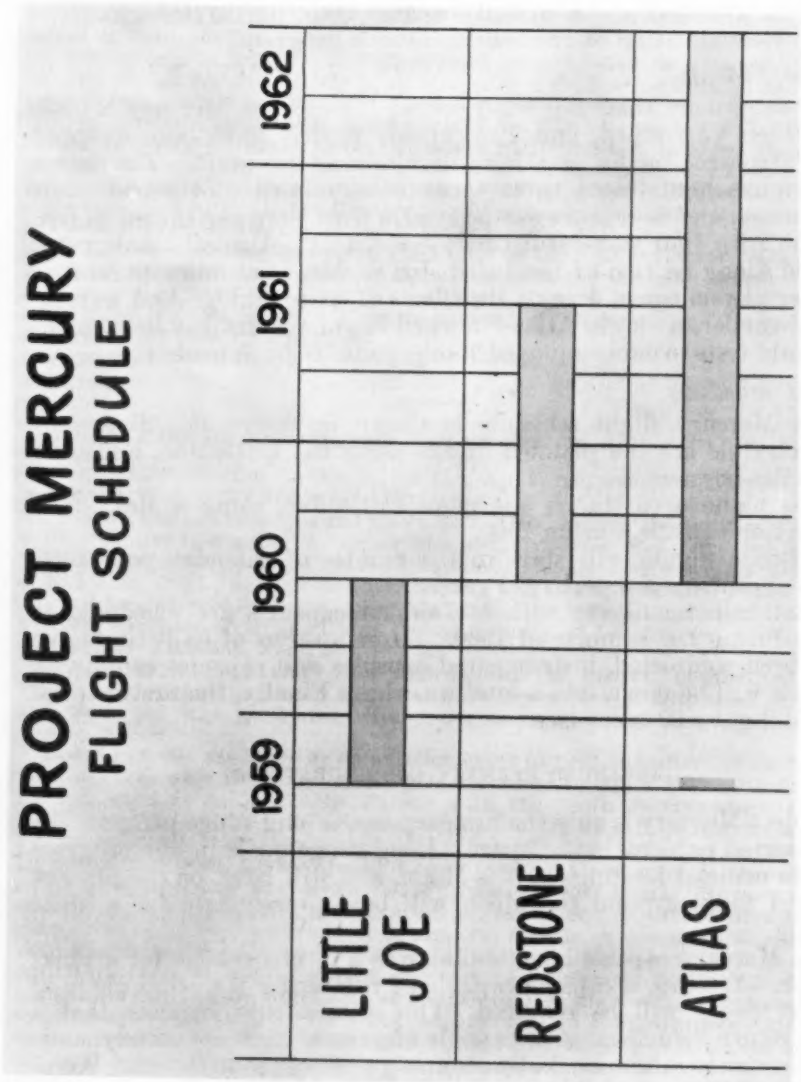


FIGURE 93.—Flight Schedule.

IV. TRACKING AND DATA ACQUISITION

By Francis B. Smith, Chief, Advanced Development, Space Flight Operation, NASA

GROUND NETWORK INSTALLATIONS

In the formulation of a national space program, of necessity the first consideration was given the problems of obtaining the propulsive power required to place satellites in orbit and to launch space probes.

This is an interesting and challenging program, and has received so much attention that little has been said about the ground installations which will be necessary for the optimum utilization of space vehicles. An effort is made here to give some feeling for the factors involved in establishing ground installation requirements as dictated by the program itself.

For the launching, the tracking, the acquisition of data, and the rapid computational effort attendant to the utilization of space vehicles, both of the Earth satellite type and for deep space probes, a complex ground installation is required.

ELEMENTS OF SPACE FLIGHT LAUNCH CONTROL AND TRACKING NETWORK

The elements of such a farflung installation are shown in figure 94.

First, there must be a launching facility. Associated with this there must be a tracking network adequate to the control of the vehicle during the launching phase. This is for safety and trajectory trimming requirements. There must also be farflung tracking networks, both electrical and optical. These are to acquire the space package after it is inserted in its path, to keep track of it during the time it is performing its mission. There must also be a telemetering capability associated with these networks to collect the scientific data acquired by the vehicle during its mission. It must also be possible to contact the vehicles at the proper times. There must be a communication network to tie together the various data-collecting stations and to bring each station into contact with the central control station at the Goddard Space Flight Center. Finally, there must be a computing center where ephemerides of the satellites and complex data reduction may be accomplished.

THE LAUNCHING COMPLEX

The first consideration in the definition of the requirements of a launch complex or complexes is the size and type of vehicles to be employed.

The NASA space program involves the launching of the following types of space vehicles:

First, Earth-circling satellites at various altitudes, using vehicles which will have thrusts of from 30,000 pounds to 150,000 pounds.

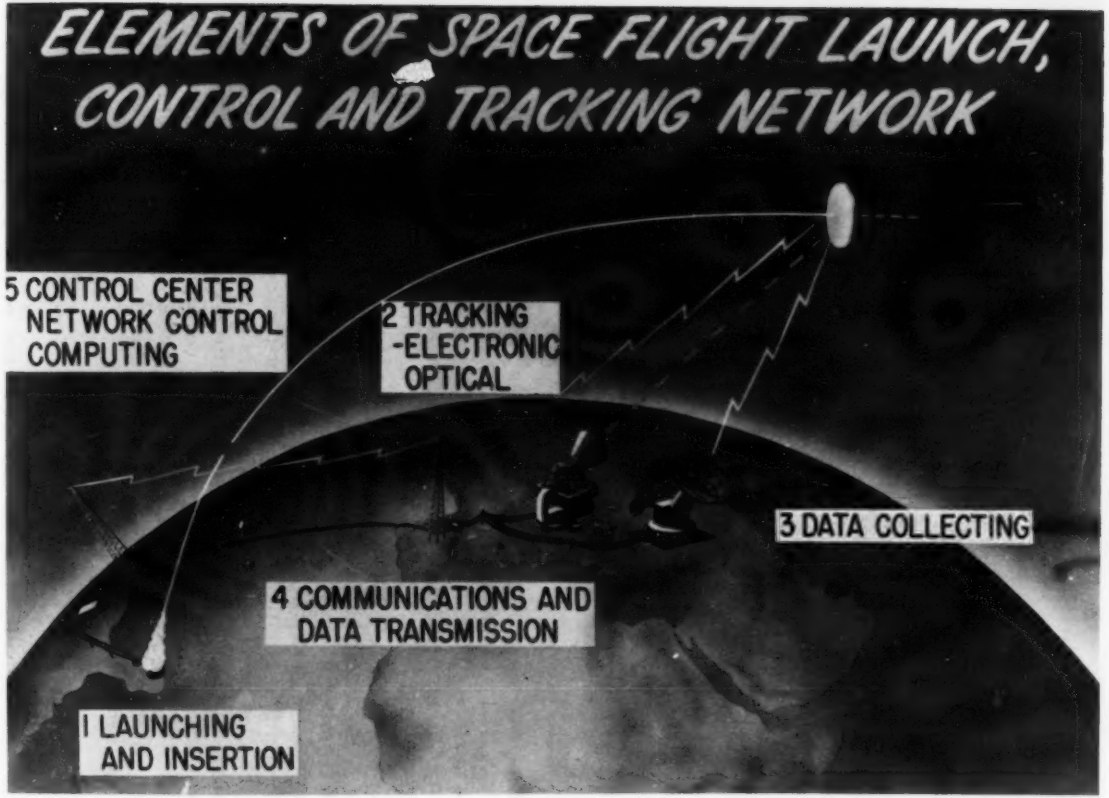

ELEMENTS OF SPACE FLIGHT LAUNCH, CONTROL AND TRACKING NETWORK
5 CONTROL CENTER NETWORK CONTROL COMPUTING
2 TRACKING -ELECTRONIC OPTICAL
3 DATA COLLECTING
4 COMMUNICATIONS AND DATA TRANSMISSION
1 LAUNCHING AND INSERTION

FIGURE 94

Second, the launching of larger Earth-circling satellites using vehicles having thrusts in the range of 150,000 pounds to about 6 million pounds.

Third, the launching of space probes using vehicles having initial thrusts in the range of 150,000 to 6 million pounds.

POLAR, EQUATORIAL AND INTERMEDIATE ORBITS

As for the orbits that are planned, figure 95 shows the various types of satellite orbits required to carry out these missions.

Three different orbits are shown. The first is an equatorial orbit, where the satellite flies in approximate circles about the Earth, just above the Equator.

The second type is a polar orbit, which is inclined at 90° to the equatorial, and where the satellite circles the Earth from pole to pole with the Earth turning under the orbit.

There is a third type which has been used in the past, and will be used in the future extensively. This is an orbit in an intermediate inclination which is then between the equatorial and the polar. For some scientific purposes this inclined orbit will be optimum.

In order to launch a satellite into a polar orbit from within the continental United States, it is clear from figure 95 that we are limited in our operations to the west coast; that is, if we are to obey the restriction that the launching vehicle shall not pass over inhabited areas of the Earth. If we attempted to launch in a polar orbit from Cape Canaveral, we would pass over inhabited areas.

For an equatorial launch, a site has not yet been chosen. This launching site, however, can be a transportable one set up on an island near the Equator, or it possibly might be on a ship.

LUNAR OR PLANETARY TRAJECTORIES

Figure 96 shows a schematic of a possible lunar or planetary probe trajectory. In its early stages it resembles very closely that of a satellite. The principal difference between a deep space probe trajectory and a satellite trajectory is one of velocity. The two trajectories are exactly similar up to this point. The deep space probe goes out at a greater velocity and therefore escapes the Earth.

For the deep space probe, the vehicle is required to attain a velocity sufficient for escape.

Now, to take advantage of the rotational velocity of the Earth, it is again advisable to launch the vehicle of this sort from as low a latitude as possible, where the rotational velocity is greatest.

For the immediate future and most possibly for many years to come, the launching vehicles used in space work will have to be multistage rockets. As indicated earlier, the ground installation requirements have to accommodate vehicles of an ever-increasing thrust level. Launching facilities will have to be designed to prepare and to service these huge devices. The thrust levels specified for the larger Earth-circling satellites and for space probes have been indicated to be as large as 6 million pounds. As an indication of the problems here, the heat energy involved in the launching of one of these large vehicles having 6 million pounds thrust has shown that in bringing it

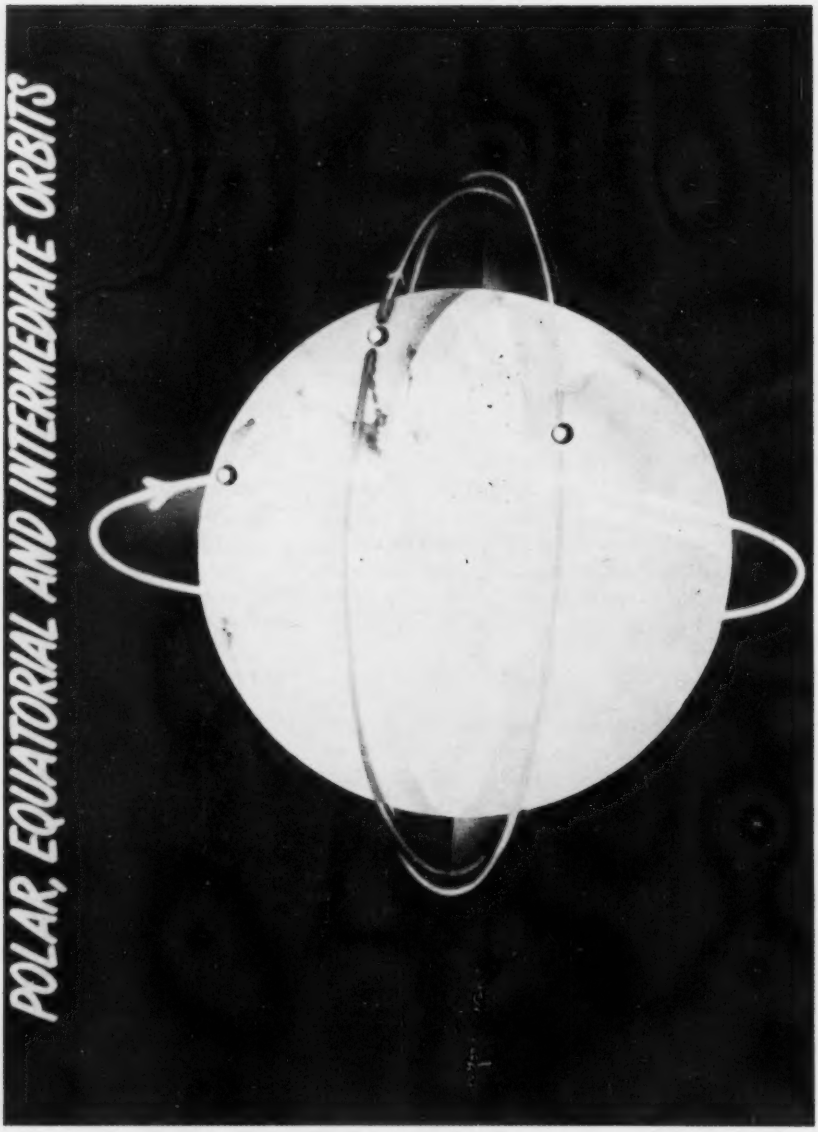


FIGURE 95

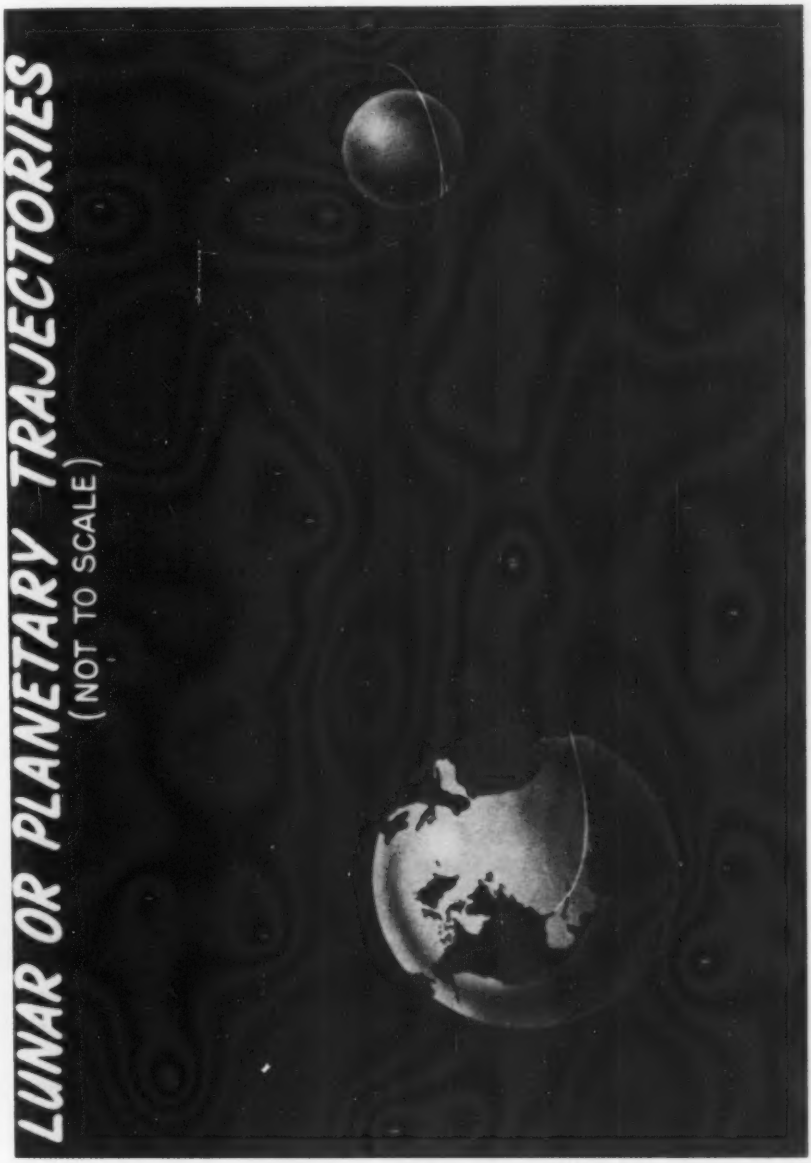


FIGURE 96

to an altitude of 50 feet above the launching pad, enough heat is generated to boil away 10,000 gallons of water.

TYPICAL LAUNCH FACILITIES

Figure 97 shows the major functions which must be performed by and the equipments which must be found at the launching site. Attention is invited first to the facilities which must be employed in the launching of the vehicle.

First, there is the launching pad, which is capable of supporting the vehicle during its time of preparation. This pad must be so equipped that it can handle and deflect the flame at the time of launching. It must also be instrumented to handle servicing equipment and provide for the necessary electrical, mechanical, and hydraulic connections involved.

Near the pad is shown a servicing structure, this gantry, which can be moved back and forth on rails. This crane is brought over the vehicle and encircles it during its assembly and installation of its equipment and during prelaunch testing. When the vehicle is ready for launching, the gantry is rolled away.

Nearby there is also a blockhouse. It is so constructed that personnel are protected against accident. It is in this blockhouse that all of the complex equipment required in the control of the operations within the vehicle during the launch preparations is located. It is also from this blockhouse that the actual firing is performed.

The hangar is usually located several miles away. The vehicle is first delivered to the hangar when it is brought to the launch site. In the hangar the vehicle is inspected for any damage during transport, and is readied for installation in the pad. In the hangar also there are workshops to provide for the repairing or replacement, as needed, of the electronic or mechanical equipment in the vehicle. Upon completion of the hangar operations, the vehicle is presumed ready to launch and is taken to the launch pad. The hangar is the home base of the launch crew. It is here that the telemetered data from the flights are analyzed and monitored during flight.

During the vehicle launching operation, the whole of the launch complex is tied together at one place in this central control. This central point is several miles, again, from the launch pad, but is closely linked by communications to the hangar, the blockhouse, the launch site, to the local tracking and telemetering facilities, and to all of the downrange stations. During the launching operation, all information is fed into the central control point, and upon the basis of this information the range officer determines that the range is ready to accept the vehicle when it is launched.

After the launching crew has brought the vehicle to the point where it is ready for the firing signal, and when an OK has been given by the range control officer at central control signifying that the range is ready to accept the vehicle, the launch is effected. Also, adjacent to the launching area is a telemetering pad where is located the electronic equipment necessary to a preliminary determination that the rocket-borne transmitting equipment is functioning properly. At this location there is also a computer which will give a quick reduction of the

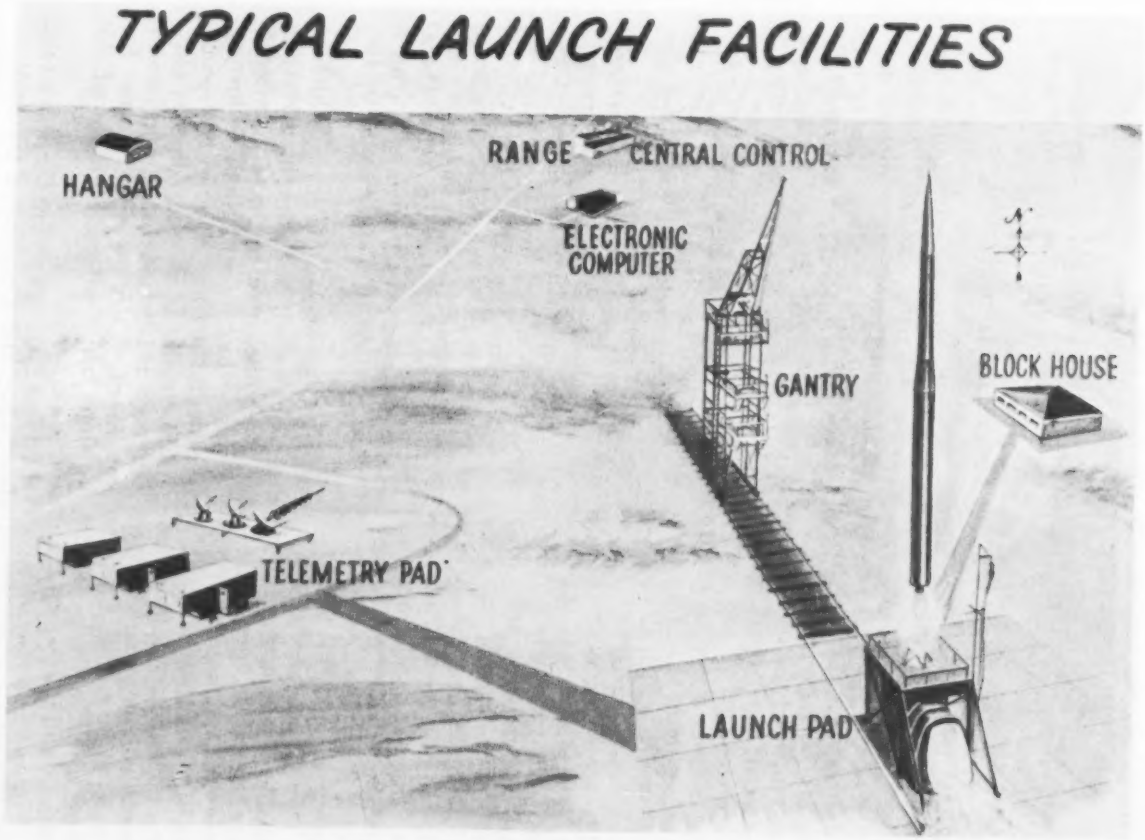

TYPICAL LAUNCH FACILITIES
HANGAR
RANGE
CENTRAL CONTROL
ELECTRONIC COMPUTER
GANTRY
BLOCK HOUSE
TELEMETRY PAD
LAUNCH PAD

FIGURE 97

telemetered data so that the crew can have an immediate understanding of the operation of the vehicle during the early phases of its flight.

Such an integrated space launching facility is in operation at the Atlantic Missile Range.

COMMAND AND ACQUISITION NETWORK GROUND STATIONS AND DOWNRANGE SUPPORTING FACILITIES

The installation will also be affected by the type of trajectory which is employed. Figure 98 shows a typical space vehicle trajectory, and will serve to illustrate some of the problems which must be solved.

The vehicle is usually launched vertically from the pad, and is allowed to fly vertically until it attains some velocity, and then the orbit is inclined slightly to move the vehicle away from the launching facility. It is allowed to proceed along this path through the denser portion of the atmosphere, and then it is programed over into the desired direction. After it gets up to a height of a hundred miles or so, it begins to program over. The direction in which it is programed is usually toward the east to take advantage of velocity. With the exhaustion of the propellants in the final stage, the satellite is on its way toward an orbit.

Its mission might be extraterrestrial; that is, it might shoot off in the direction of the Moon or a planet. Or it can be an Earth-circling satellite, for which it has a somewhat lower velocity, but still high enough to balance out the gravitational forces of the Earth.

The launching operation starts at Cape Canaveral, and it continues for a distance of approximately a thousand miles downrange. Throughout the whole of this launching operation, the launch crew must maintain contact with the vehicle, as shown in our chart. The trajectory is shown somewhat to scale against the curved Earth.

The location of the various downrange stations which must be outfitted to provide a sufficiently complete range to launch such a vehicle are indicated. Starting at the launch site at Cape Canaveral, there must be telemetry stations capable of receiving the signals transmitted from the rocket during the operation of the first and of the second stages at this point.

There must also be a minitrack or a doppler radio device which is capable of measuring the instantaneous velocity of the vehicle during its entire trajectory. Also near the launch pad we have installed a powerful and accurate tracking radar which is capable of following the flight of the vehicle at least through the completion of the second stage operation. Associated with this radar is a large, complex electronic computer so that the computed predictions of the trajectory can be given to the launching crew in essentially real time in order for them to make the necessary decisions which affect the flight of the vehicle, and these must be effected in this area.

Figure 98 shows the island of Grand Bahama where there is a telemetry facility, a second tracking radar, and a command transmitter. It is through this command transmitter that the flight of the vehicle may be varied. Not all of the vehicles are planned in the same way. Many vehicles have an inertial guidance and a control system which is contained in the vehicle itself. In the vehicle and in the ground

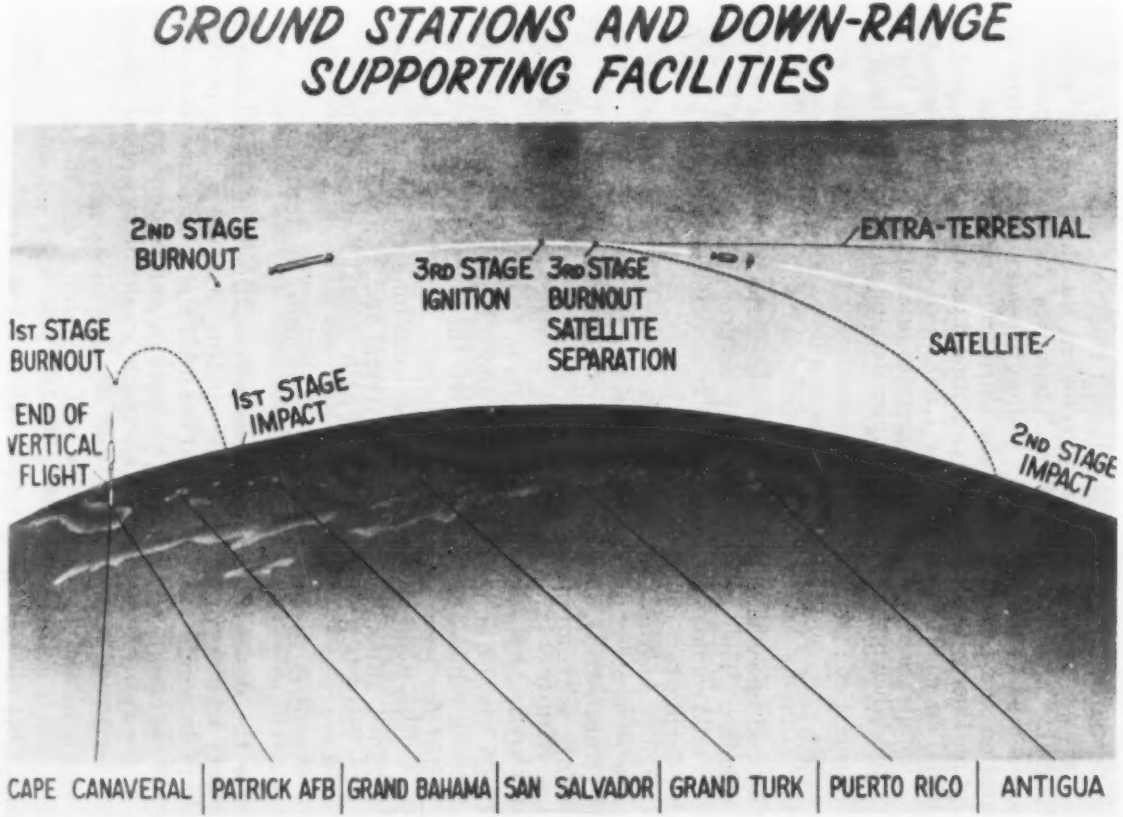

GROUND STATIONS AND DOWN-RANGE SUPPORTING FACILITIES
2ND STAGE BURNOUT
EXTRA-TERRESTIAL
3RD STAGE IGNITION
3RD STAGE BURNOUT SATELLITE SEPARATION
1ST STAGE BURNOUT
SATELLITE
1ST STAGE IMPACT
END OF VERTICAL FLIGHT
2ND STAGE IMPACT
CAPE CANAVERAL
PATRICK AFB
GRAND BAHAMA
SAN SALVADOR
GRAND TURK
PUERTO RICO
ANTIGUA

FIGURE 98

facility, there is provided, however, equipment which allows the ground crew to modify the direction of flight if they determine that the operation of the vehicle is such as to require it.

The next downrange station is on San Salvador. This is equipped with a telemetering station and another set of command transmitters.

Further down the line, there is a station on Grand Turk. Here again, detailed information is gathered from the vehicle and a minitrack ground station capable of tracking the flight of the vehicle is located. Also at Grand Turk, there is a command transmitter which is used as the last chance station to send signals directing the separation and the ignition of the third stage of the vehicle.

Out on Puerto Rico there is an additional telemetry station, and on Antigua, an island some 1,100 or 1,200 miles downrange, there is a prime minitrack receiver. This operates in conjunction with Grand Turk to gather telemetry and doppler data on the flight of the third stage.

COMPLEX FACILITY REQUIRED FOR EACH LAUNCHING SITE

The trajectory and the sequence which the vehicle must follow are complex. They must be carefully monitored, and it must be possible to send commands to the vehicle at any time during the powered flight, during this thousand-mile trajectory.

A facility such as has been described above, which consists of all of these elements at the launching site, and the complex telemetering, radar, transmitting, and tracking stations stretched out along the long trajectory is required for each launching site. We presently have such a facility at Cape Canaveral. A similar one is required at the Pacific Missile Range at Point Arguello in California.

NASA has also an installation at Wallops Island in Virginia. Here small space vehicles can be launched, but the larger liquid rockets are not suited for launching at this location. The launching facilities which will be required for the heavier launching vehicle are not now in existence, although the Cape Canaveral and Point Arguello locations are suitable for the meeting of such orbital requirements.

VEHICLE MUST BE TRACKED AFTER ORBIT IS ACHIEVED

Once the desired orbit has been accomplished, it then becomes necessary to observe, or track, the satellite or space vehicle periodically to determine the elements of the orbit and to measure perturbations or changes in the orbit. This tracking can be done normally in one of the two ways: either by electronic means or by optical means, as are illustrated in figure 94 on page 748.

PHOTOGRAPHIC SATELLITE TRACKING

Figure 99 (p. 758) shows one of the Baker-Nunn cameras used for optical tracking. This instrument tracks by taking a photograph of the satellite against the star background. Such a photograph appears as shown in figure 100 (p. 759). By carefully measuring the position of a satellite in relation to the stars at various instants of time, it is possible to determine its position very accurately. Using this information, it is then possible to calculate its orbit.

The present locations of the tracking cameras just shown are illustrated in figure 101. There are 12 of them that are located in the various countries shown. All are concentrated between northern and southern latitudes of about 35 degrees. The reason for this is that they were positioned to track U.S. satellites which had an inclination of 35 degrees or better, and so, therefore, they will not provide coverage which would be needed for the higher inclination satellites. These cameras are limited in that they are useful only during dawn or dusk conditions, and of course during clear weather conditions.

MINITRACK STATIONS

For more universal tracking which is available day or night and under any weather conditions, we turn to electronic means, and figure 102 illustrates one of the minitrack stations, which is the primary electronic means of tracking. This station operates by receiving a radio signal which is transmitted by a very lightweight transmitter in the satellite, and the satellite's position is determined by a comparison of the signals which are received by the various antennas which make up the station. The antennas are illustrated in the closeup photograph shown at the bottom of the figure. This method is not quite as accurate as the optical method, but the data read-up methods are much faster and it is useful under any weather conditions.

The locations of the minitrack stations are illustrated on the map shown in figure 103. There are some 12 stations. Most of the stations are located in a north-south line, again between 35° south latitude and 35° north latitude—appropriate locations for tracking satellites which are in low inclination orbits. A satellite whose orbit is inclined at 30° to the Earth's equator would pass near one of the stations in this net at least once each orbit. The other two stations in Australia and South Africa are useful in giving a better determination of the initial orbit.

Another function that must be provided by the ground network is that of data collecting. All U.S. satellites have a transmitter, a so-called telemetry transmitter, which sends down scientific information or possibly TV information which must be received by the ground station. Since the power transmitted is very low, it requires special, very sensitive receiving equipment and high gain antennas on the ground for this purpose.

LUNAR PROBE ANTENNA

Figure 104 illustrates two types of antennas which are used. This is a large parabolic antenna. The purpose of the dish shape is to reflect the radio signals back to the feed antenna, which is located at the focal point of the parabola. This antenna is 60 feet in diameter. Another simpler type, but somewhat less effective, is the so-called quadrihelix, which also gives more gain than one would get with an ordinary type of receiving antenna. In both cases these antennas must be pointed directly at the satellite as it passes overhead, because they are insensitive if the satellite gets out of the beam of the antenna. There are two in Hawaii, one in Florida, one in California, and a few others downrange on the Atlantic Missile Range.

53795 O—60—pt. 2——13

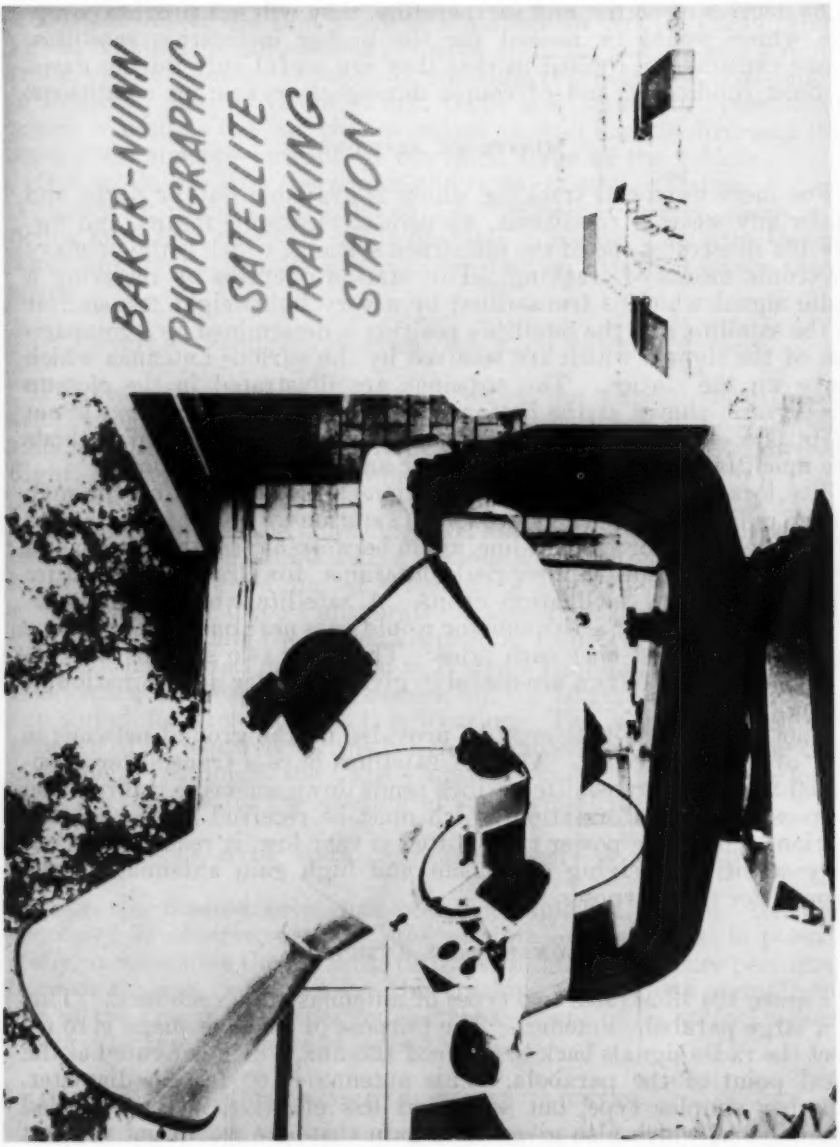


FIGURE 99

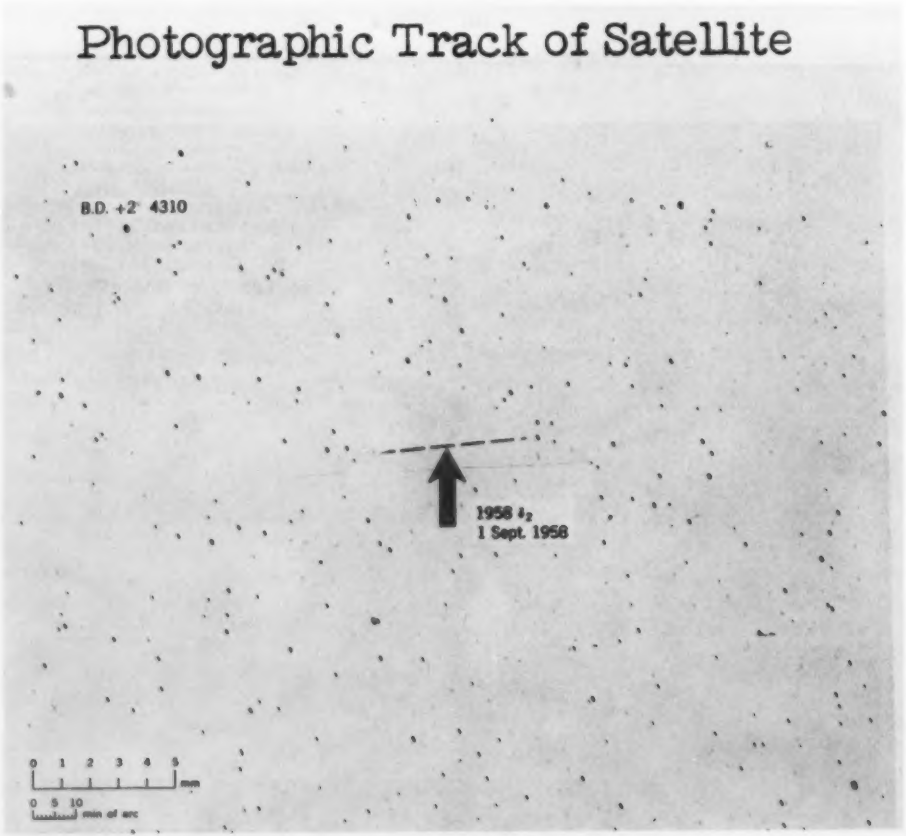

Photographic Track of Satellite
B.D. +2° 4310
1958 δ_2
1 Sept. 1958
0 1 2 3 4 5
mm
0 5 10
min of arc

FIGURE 100

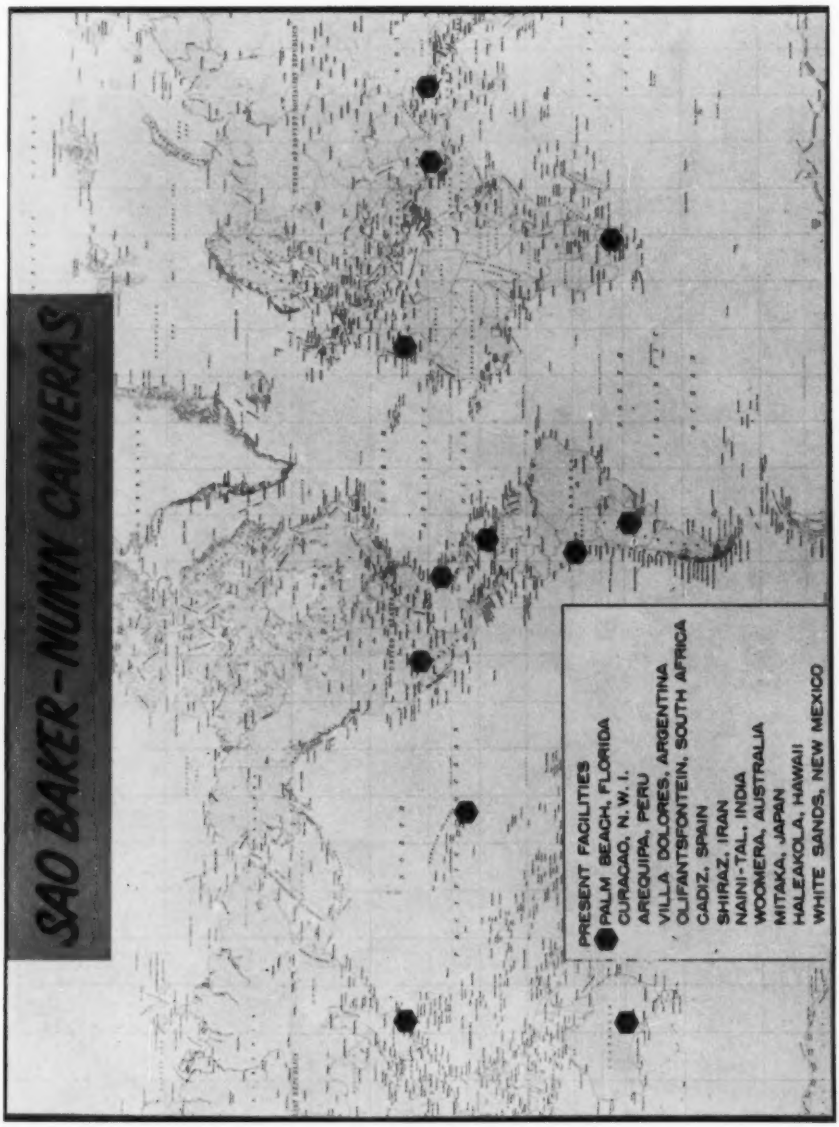

SAO BAKER-NUNN CAMERAS
PRESENT FACILITIES
PALM BEACH, FLORIDA
CURACAO, N.W.I.
AREQUIPA, PERU
VILLA DOLORES, ARGENTINA
OLIFANTSFONTEIN, SOUTH AFRICA
CADIZ, SPAIN
SHIRAZ, IRAN
NAINI-TAL, INDIA
WOOMERA, AUSTRALIA
MITAKA, JAPAN
HALEAKOLA, HAWAII
WHITE SANDS, NEW MEXICO

FIGURE 101

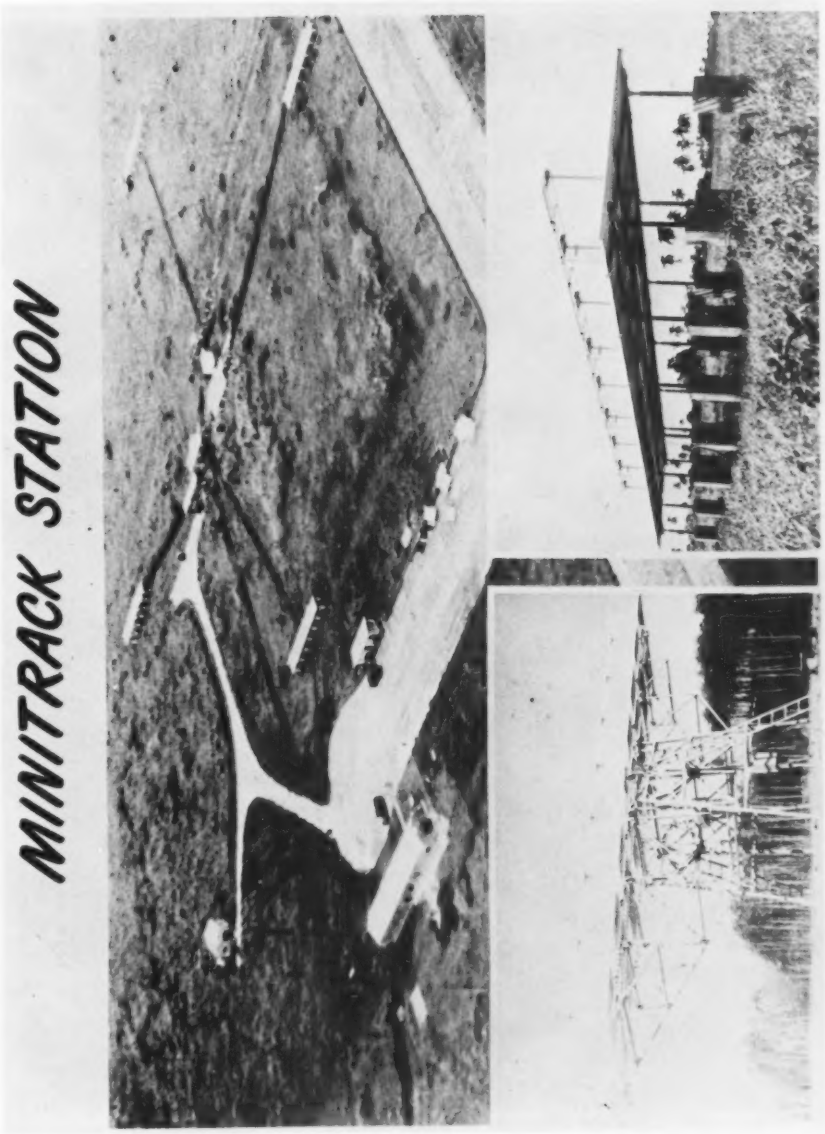


FIGURE 102

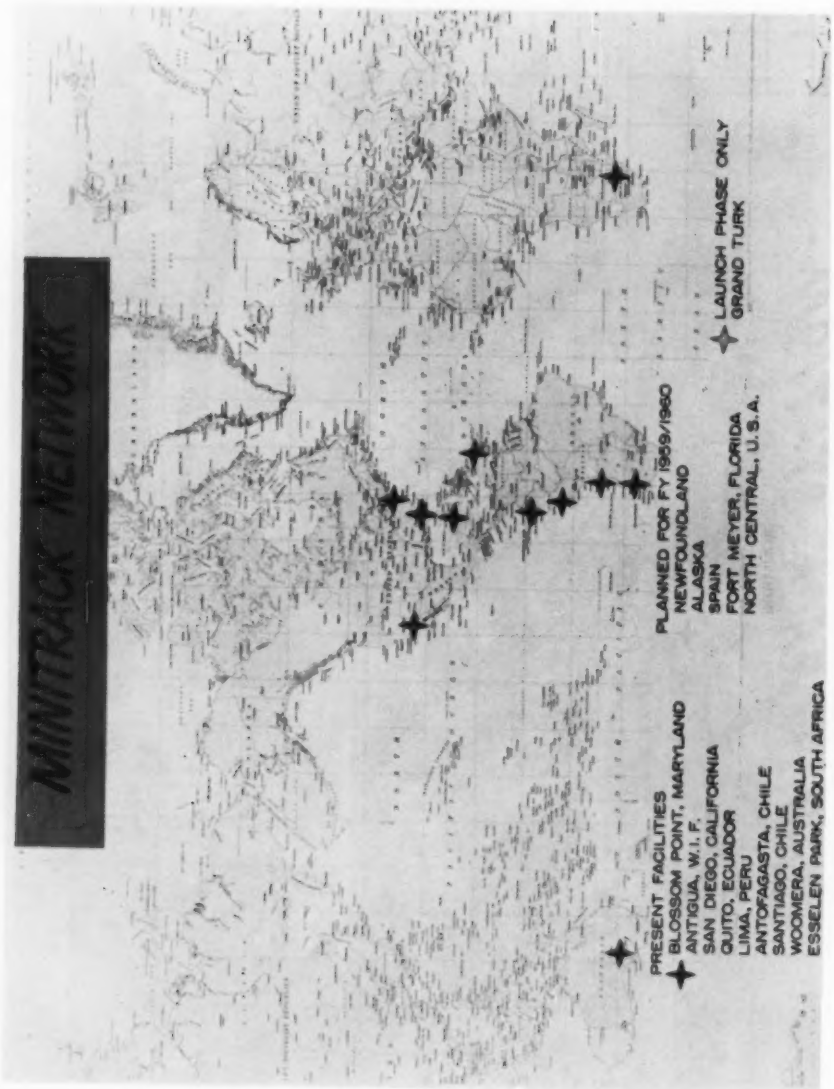

MINITRACK NETWORK
PRESENT FACILITIES
BLOSSOM POINT, MARYLAND
ANTIGUA, W.I. F.
SAN DIEGO, CALIFORNIA
QUITO, ECUADOR
LIMA, PERU
ANTOFAGASTA, CHILE
SANTIAGO, CHILE
WOOMERA, AUSTRALIA
ESSELEN PARK, SOUTH AFRICA
PLANNED FOR FY 1959/1960
NEWFOUNDLAND
ALASKA
SPAIN
FORT MEYER, FLORIDA
NORTH CENTRAL, U.S.A.
LAUNCH PHASE ONLY
GRAND TURK

FIGURE 103

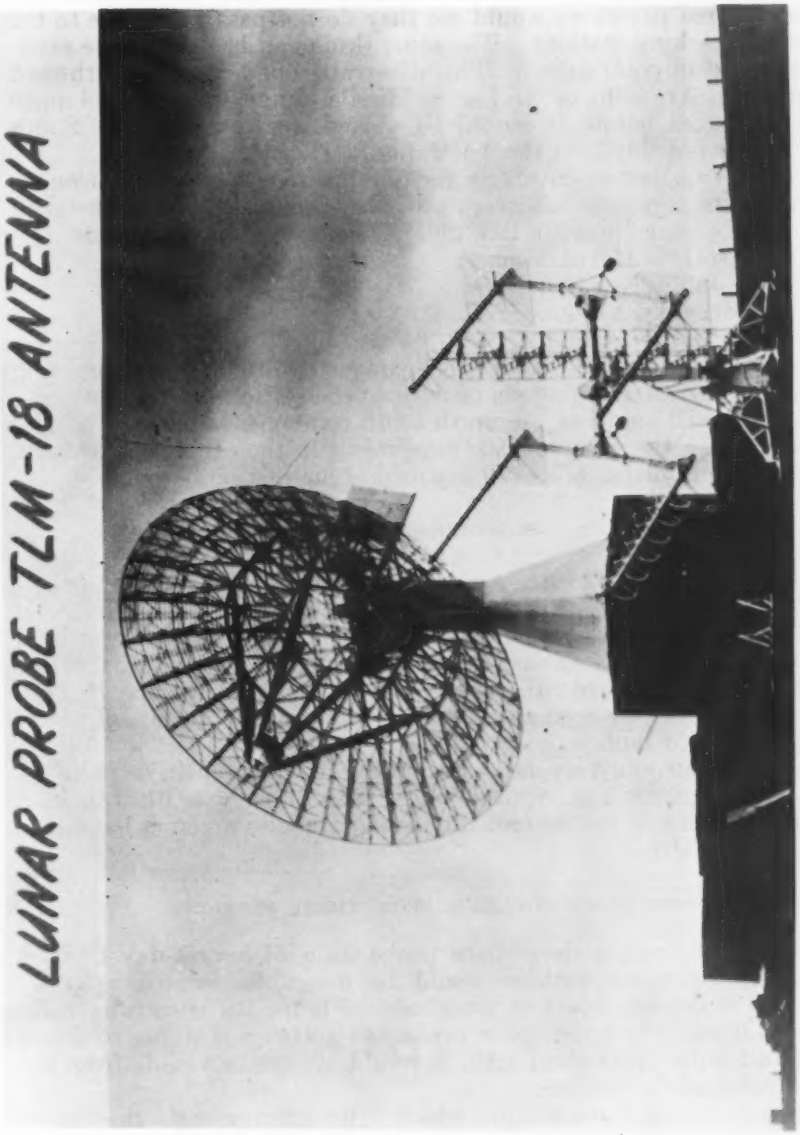


FIGURE 104

FIGURE 103

HIGH INCLINATION ORBITS

Figure 105 illustrates the path of satellites which have a higher inclination—in this case it is 51°—and you will note if we traced out each of these passes we would see they do not pass very close to the existing tracking stations. The same thing can be said of the satellites placed in polar orbits. This illustrates one launched southward from Point Arguello, or the Pacific Missile Range, which would make several passes before it would be picked up by either the South African or possibly later the Australian station.

To provide better coverage for satellites in high inclination or polar orbits, four new minitrack stations are currently being installed and will be operational in late 1960. The station locations are:

East Grandforks, Minn.
St. Johns, Newfoundland.
Fairbanks, Alaska.
Southern England.

In addition to these new stations, an east-west component is being built into the antenna pattern of most of the stations of the minitrack net. This will augment the north-south component and will, in conjunction with the four new stations, result in the capability to track properly equipped satellites in any orbital inclination.

GOLDSTONE ANTENNA

Other programs which are being undertaken include lunar probes and planetary probes. The problem here is instead of trying to receive signals from satellites which may be a few hundred miles—or at most a few thousand miles—away, we will be trying to receive signals from space probes which are millions of miles away and which may be radiating no more power than is normally consumed by an ordinary household light bulb.

For this purpose very large antennas and ultrasensitive radio receiving equipment are required. One such antenna is illustrated in figure 106; this is the 85-foot diameter parabolic antenna located at Goldstone, Calif.

DEEP SPACE COVERAGE FROM THREE STATIONS

Ideally, to track a deep-space probe on a 24-hour-a-day basis, a minimum of three stations would be desirable, located approximately 120 degrees apart in longitude. Figure 107 illustrates three such stations. Once the space probe has gotten a distance of a few thousand miles from the Earth, it would always be visible from one or the other of the stations.

The sites of the three stations which will compromise the deep space net are:

Goldstone, Calif.
Woomera, Australia.
Johannesburg, South Africa.

Goldstone is currently operational; Woomera will be operational late in 1960 and the South African station, when it becomes operational in early 1961, will complete the net.

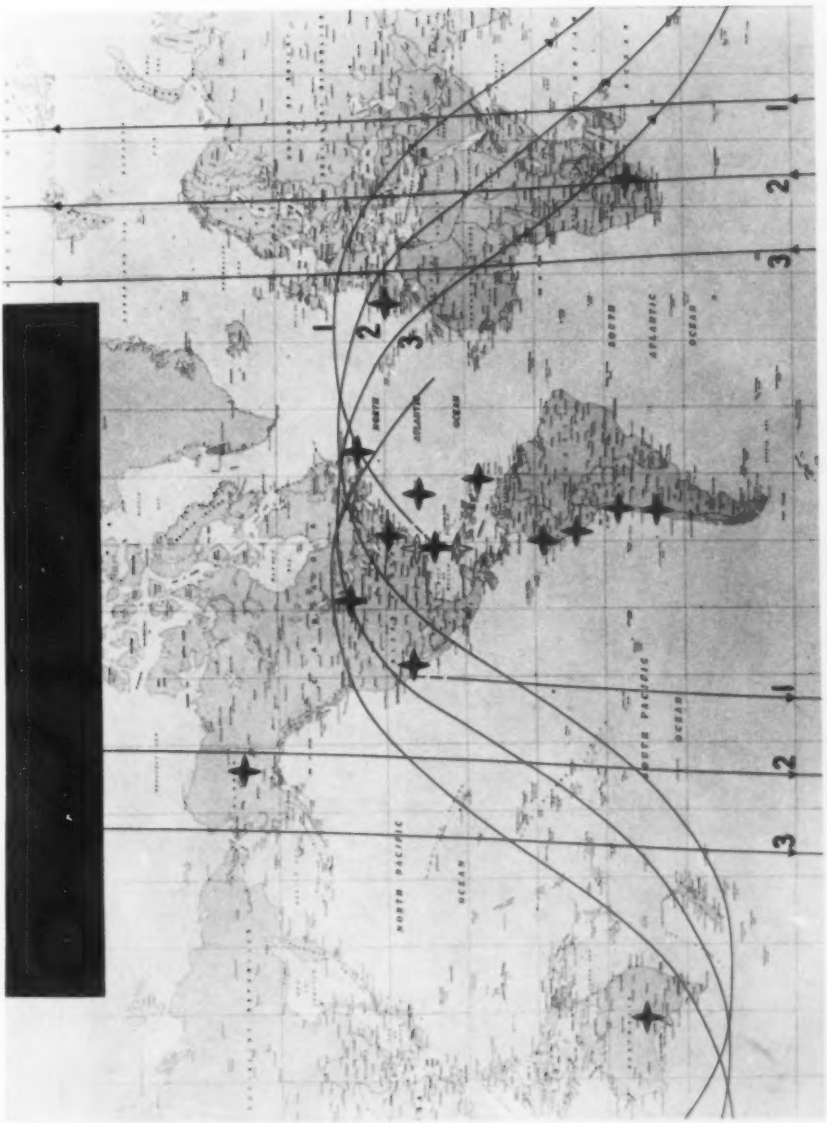

1
2
3
1
2
3
1
2
3
NORTH ATLANTIC OCEAN
NORTH PACIFIC OCEAN
NORTH PACIFIC OCEAN

FIGURE 105

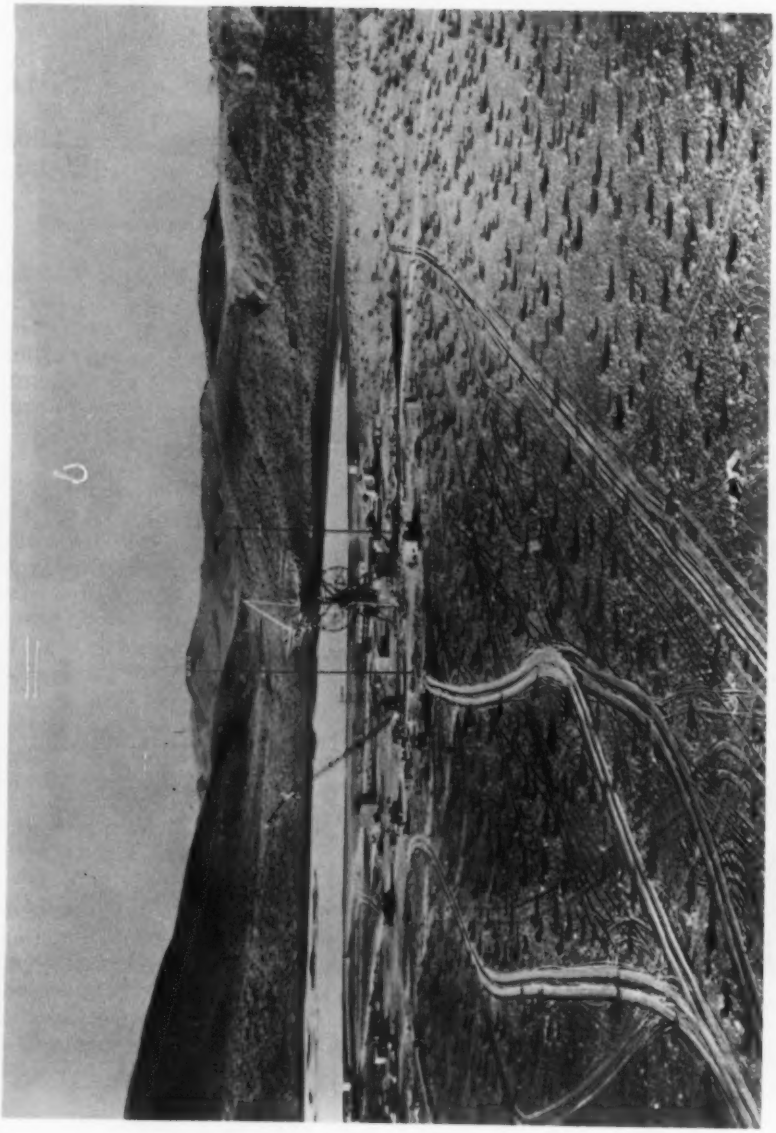


FIGURE 106.—Eighty-five-foot diameter parabolic antenna located at Goldstone, Calif.

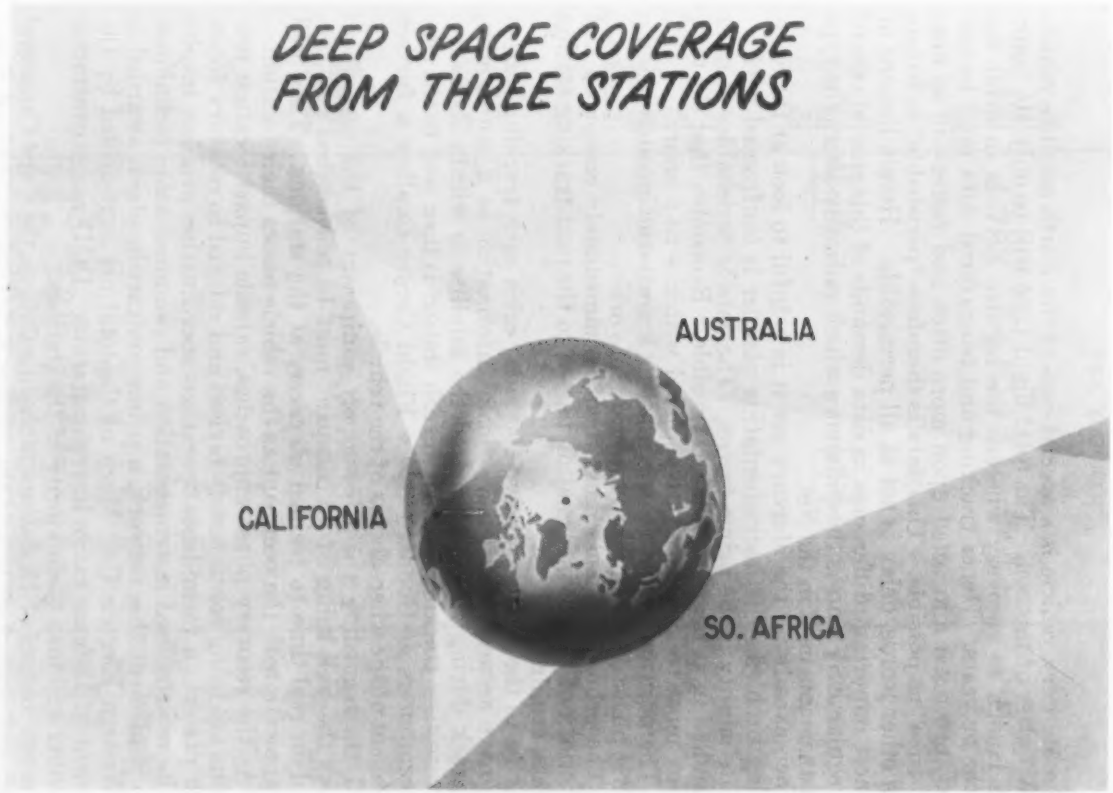

DEEP SPACE COVERAGE
FROM THREE STATIONS
AUSTRALIA
CALIFORNIA
SO. AFRICA

FIGURE 107

These stations are being established to provide continuous coverage of space probe vehicles and support an essential portion of the NASA deep space and lunar exploration programs. The stations will also be used in the meteorological and passive communication satellite programs.

MERCURY NET

The Mercury vehicle is a special case of the Earth satellite vehicle (ESV) class of mission. The total flight time will be only 4½ hours from launch to recovery whereas the regular ESV is in orbit for months or years. Hence tracking and telemetered data must be collected, processed and acted upon more often and faster—in as near "real-time" as possible. This data is therefore "perishable" in nature or, in other words, delay is not at all permissible. Herein lies one of the most important differences in data demands of this special case of the regular ESV and is the difference which radically alters the type of instruments used in the Net.

When examining the Mercury net it is helpful to look at the engineering problems the instrumentation planner is confronted with:

1. Reliability is the prime factor. The data is perishable—it must be handled in as near real time as possible. Remember that the total mission must be successfully completed within 4 to 5 hours.
2. The position of the vehicle must be known continuously during the first phase of the flight to injection into orbit.
3. The orbital elements must then be immediately computed and predictions of "look" information passed to the next tracking station so it can acquire.
4. Due to the relatively low (100-mile) orbit each tracking station must have accurate and timely "look" information so it can acquire, and track during the short period the satellite is within its range. The resulting tracking data from each station is then sent to the central computers at Goddard Space Flight Center to allow a further refinement of the whereabouts of the vehicle.
5. Data regarding the life-support equipment of the capsule as well as the well-being of its occupant must be telemetered and presented in real-time to trained observers at the stations. They will communicate with the occupant as the vehicle passes their location.
6. As the recovery phase approaches, capsule impact location predictions are being continuously revised and relayed to recovery forces which presents a formidable operations coordination problem involving the most refined instrumentation and communication techniques.

To implement this network, a prime contract has been awarded to the Western Electric Co. Much of the total net is provided by Department of Defense range instrumentation. DOD range contractor personnel will man the majority of the stations.

The net consists of 18 stations including 2 ships, the Cape Canaveral launch and control point and the computing center at Goddard Space Flight Center. The list of station locations and major equipment is shown in figure 108.

The design philosophy of the Mercury net was (first) to make use of all applicable existing instrumentation and, (second) to use a temporary-movable-concept in the creation of those stations that may have no continued value in their Mercury net location at the comple-

Telem-

		Long-range S-band radar	FPS-16 C-band radar	Telemetry and communication with capsule	Command Control	Computing
1.	Cape Canaveral (AMR)*	-	[X]	X	[X]	-
1a.	Grand Bahama (AMR)*	-	-	X	[X]	-
1b.	Grand Turk (AMR)*	-	-	X	[X]	-
2.	Bermuda	X	X	X	X	X
3.	Mid-Atlantic Ship	-	-	X	-	-
4.	Grand Canary	X	-	X	-	-
5.	Kano, Nigeria	-	-	X	-	-
6.	Zanzibar	-	-	X	-	-
7.	Indian Ocean Ship	-	-	X	-	-
8.	West Australia	X	-	X	X	-
9.	Woomera, Australia	-	[X]	X	-	-
10.	Canton Island	-	-	X	-	-
11.	Hawaii (PMR)**	[X]	[X]	X	[X]	-
12.	Southern California (PMR)**	[X]	[X]	X	[X]	-
13.	West Mexico	X	-	X	X	-
14.	White Sands Missile Range	-	[X]	-	-	-
15.	South Texas	X	-	X	-	-
16.	Eglin (AFATC)	[X]	[X]	-	-	-
17.	Computing and Communications Goddard Space Flight Center, Beltsville, Md.					X
18.	Control Center, Cape Canaveral (AMR)					X

NOTE: [X] existing facilities being utilized.
* AMR: Atlantic Missile Range
** PMR: Pacific Missile Range

FIGURE 108.—List of Mercury stations.

tion of this current program. It may be that follow-on manned missions will require relocations of stations—planning is toward this eventuality.

The Mercury net is currently being installed. Upon its completion early next year, it will be capable of tracking and telemetry coverage of a 32.5° orbit originating at Cape Canaveral with a maximum of 3 orbits.

TRACKING RADAR

Figure 109 illustrates the type of equipment which will be installed at some of these stations. This is an FPS–16 tracking radar. This has a dish similar to the previous antennas, except it is much smaller. In this case we are measuring both the angles to the vehicle and also the distance or the range to the vehicle so that the orbit can be determine within a very short time.

COMMUNICATIONS AND DATA TRANSMISSION

We will here cover the problems of communications and data transmission and the operations of the control center and the computing center itself.

The objective of a network is to bring back the tracking data so that by computation we can determine mathematically the orbit itself and, in terms of flight data or telemetry data, obtain data in the form and quantity required by the scientists and engineers for whom the whole satellite or space vehicle program is being operated.

The nerve center of a network of this sort is the control center itself. This provides the administrative and technical control of the complete network operation, provides the point of contact with associated activities that either provide data into the network or require data from the network, and it provides the data and communications relay point for the network.

BASIC VANGUARD MINITRACK COMMUNICATIONS NETWORK

On fig. 110 we have a typical communications network such as is required for global tracking networks. An example is the minitrack, the communications network associated with the minitrack tracking network. The reason for this is that it is not only typical, but it has been in operation since September of 1957.

This communication network utilizes landlines, cables, teletype systems, and multichannel systems to transmit the data to the control center. All of our data and all of our administrative and technical control are done by teletype. We have many auxiliary contact points, like the Army Map Service.

The minitrack network consists of Blossom Point, Md.; Fort Stewart, Ga.; two at Air Force Missile Test Center; four stations in South America—Quito, Lima, Antofagas, Santiago; a station in South Africa; a station in San Diego, Calif., and a station in Woomera, Australia. These are additional contact points.

FIGURE 109

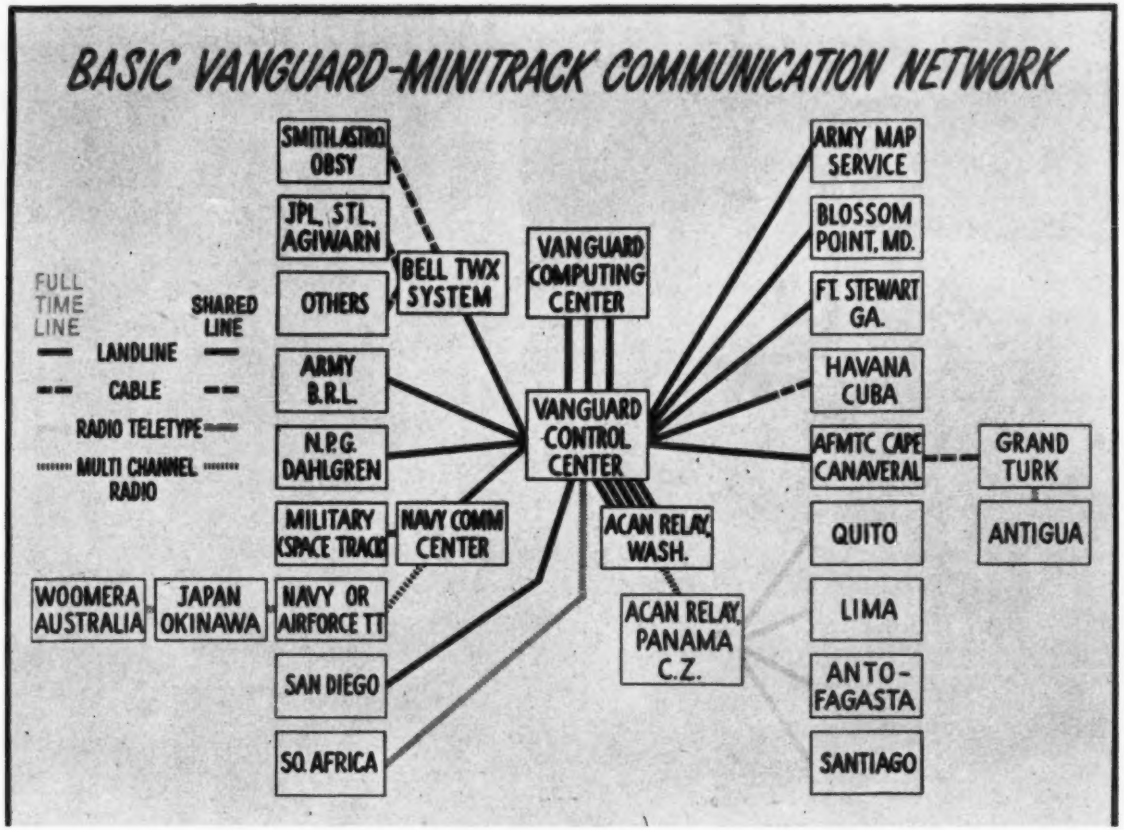

BASIC VANGUARD-MINITRACK COMMUNICATION NETWORK
SMITHSONIAN OBSY
JPL, STL, AGIWARN
OTHERS
BELL TWX SYSTEM
VANGUARD COMPUTING CENTER
ARMY MAP SERVICE
BLOSSOM POINT, MD.
FT. STEWART GA.
HAVANA CUBA
ARMY B.R.L.
N.P.G. DAHLGREN
VANGUARD CONTROL CENTER
AFMTC CAPE CANAVERAL
GRAND TURK
ANTIGUA
MILITARY (SPACE TRACK)
NAVY COMM CENTER
ACAN RELAY, WASH.
QUITO
WOOMERA AUSTRALIA
JAPAN OKINAWA
NAVY OR AIRFORCE TT
ACAN RELAY, PANAMA C.Z.
LIMA
SAN DIEGO
ANTO-FAGASTA
SO. AFRICA
SANTIAGO
FULL TIME LINE
SHARED LINE
LANDLINE
CABLE
RADIO TELETYPE
MULTI CHANNEL RADIO

FIGURE 110

TYPICAL NETWORK DATA FLOW CHART

In this network we have the typical data flow illustrated in figure 111. From all of our tracking stations—the minitrack, optical stations, military tracking groups, and university cooperating groups—we obtain many different types of raw tracking data. Our operations require them particularly in the forms of angles with free systems, frequencies, and ranges.

This data goes to the control center, where there is a data review, communications control, and from there it is sent immediately to the computing center. The computing center is connected with their lines in the communications chart.

At the computing center the raw data is put into an IBM 704 electronic calculator, and it comes out as orbital data in the form of station predictions, Equator crossings, raw minitrack data and ephemerides—the timetable prediction of the satellites, for orbital elements and precision, definitive orbits of satellites that have gone by in the past.

Our user groups include our own tracking stations; we give them information as to when the next events will occur and where to look. These include the Smithsonian Astrophysical Observatory, which is responsible for the optical tracking stations. These need precise times, positions, and rates to enable them to direct their optical instruments at the satellite.

Similarly, we give the information to the military, to Government agencies, to world wide observers, and to the universities, amateurs, commercial groups, the press, radio, and TV.

FIGURE 110

MINITRACK CONTROL AND COMPUTING FACILITIES

Figure 112 shows the communications room at the control center. The control center has a number of teletype machines. It handles on the order of 50,000 formal data messages a year. It has sent down over 6,000 formal messages a year. It has sent to the computing center over 6,000 formal data messages, and this puts it in the category of in the upper brackets of such communication relay centers in the country today.

The bottom portion of figure 112 is a picture of the IBM 704 computer located at the Naval Research Laboratory.

TYPICAL NETWORK DATA FLOW CHART

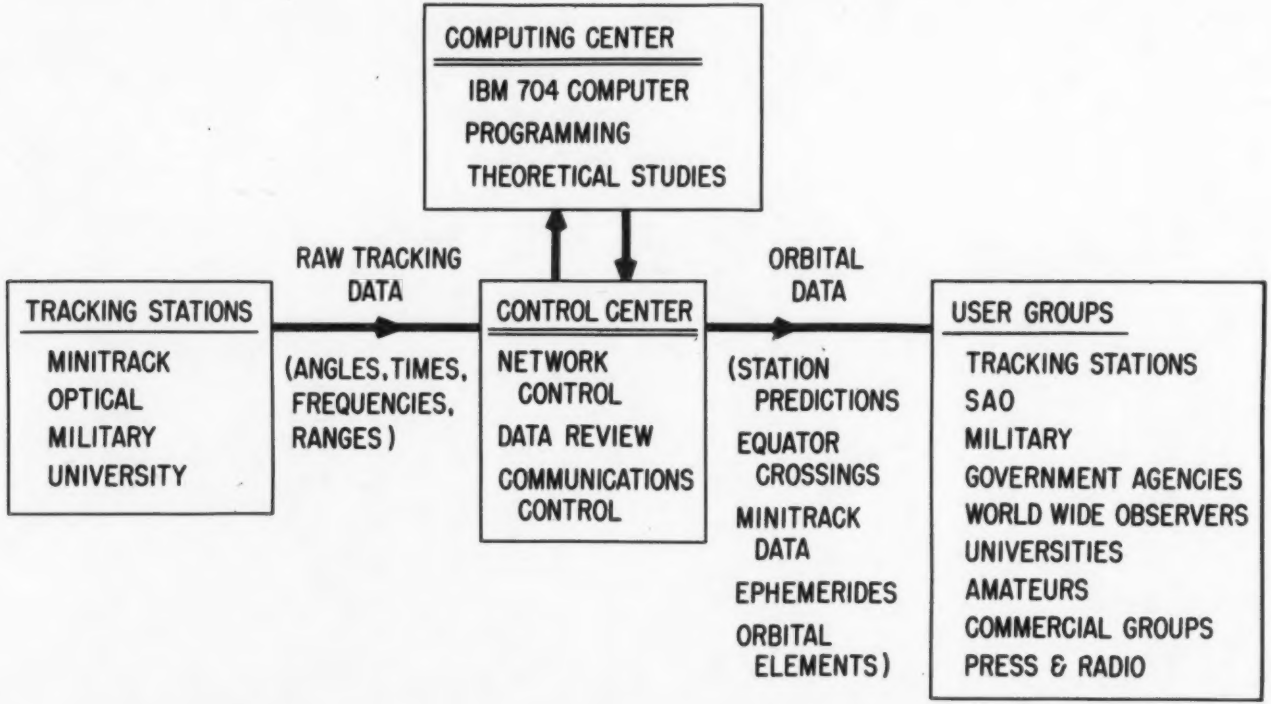


FIGURE 111

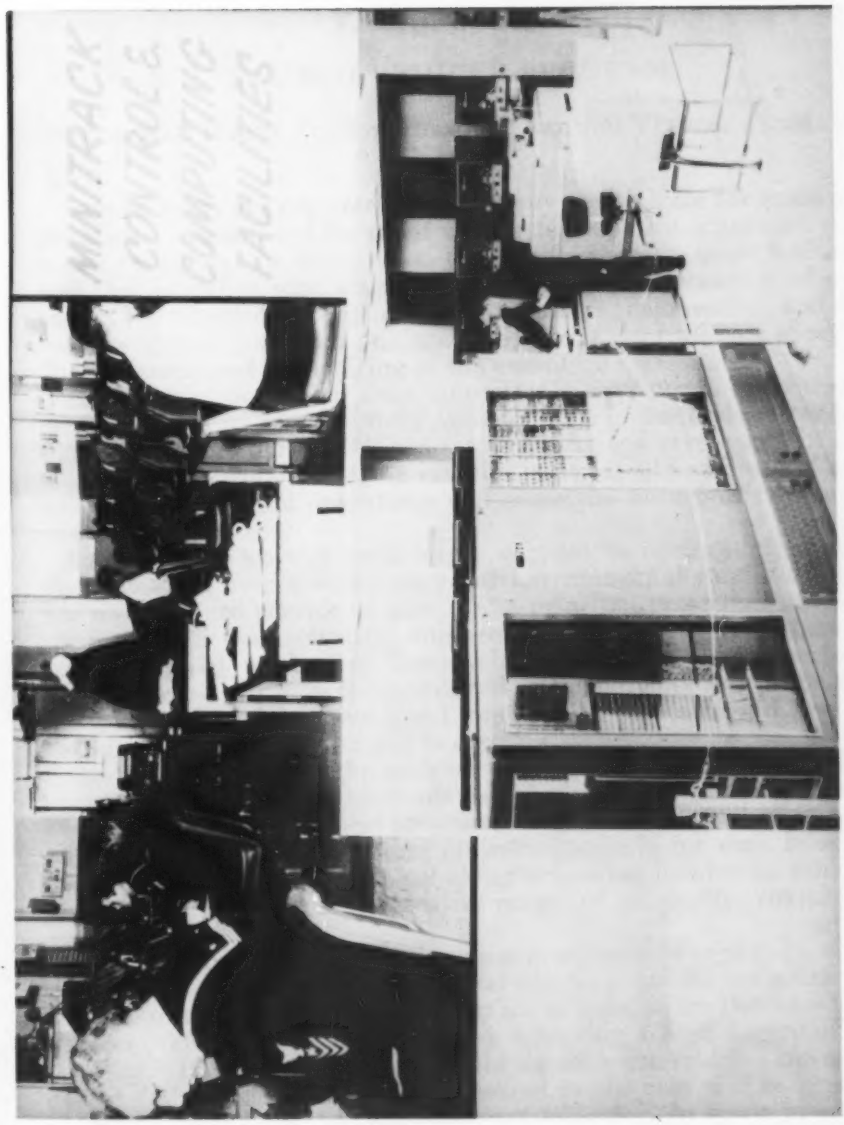


FIGURE 112

FIGURE 111

V. PROPULSION

LAUNCH VEHICLE PROGRAM

By Abraham Hyatt, Deputy Director, Launch Vehicle Programs, NASA

Several years are required to perfect any new vehicle for space application. The state of the art of vehicle development is not such that a new vehicle can be designed on the drawing boards, manufactured, and then launched with an expectation of a high probability of success in the mission. A vast amount of research, engineering, and development goes into each one, and the adequacy of all this effort is finally determined in the firing of the assembled system.

Hundreds of operations must take place in sequence in order that a missile launching may be fully successful. For example, after the signal to fire is given, 144 sequential operations take place in the launching of a Juno II with a satellite payload. The failure of any one of the sequential operations will cause the failure of the entire effort.

In the future we will build larger vehicles, to perform more complex missions, over a wider range of environmental conditions and for much longer periods of time. The principal point that must be appreciated is that scientific, engineering, and manufacturing manhours required to develop these vehicles will multiply manyfold. More vehicles will have to be assigned to the development phase and more vehicles to do a given job, if we want to have a high degree of confidence that the mission will be accomplished.

An understanding of the state of the art in vehicle development is necessary to appreciate the fundamental philosophy in the planning of a national launch vehicle program. This principle is that, instead of designing a specialized and optimized vehicle for each mission, every effort is being made to develop the smallest number of vehicles which will encompass the entire range of presently envisioned missions.

The objective of the NASA is to use every vehicle type for a number of missions even though the vehicle may not be optimum for any one of the missions. This allows us, in time, to use the same type vehicle over and over again, thereby achieving a high degree of reliability. If we achieve a high reliability with our vehicles, the number of failures that we have experienced in the past will be greatly reduced; the dollars that are made available for the space program will permit greater accomplishments; and our standing in the field of space exploration relative to other nations will be enhanced.

Figure 113 depicts all the vehicles that NASA is now using or plans to use in its future programs. Several vehicles are for short-term use only. They are the vehicles that have been quickly put together with components from military missile programs and the Vanguard IGY vehicle.

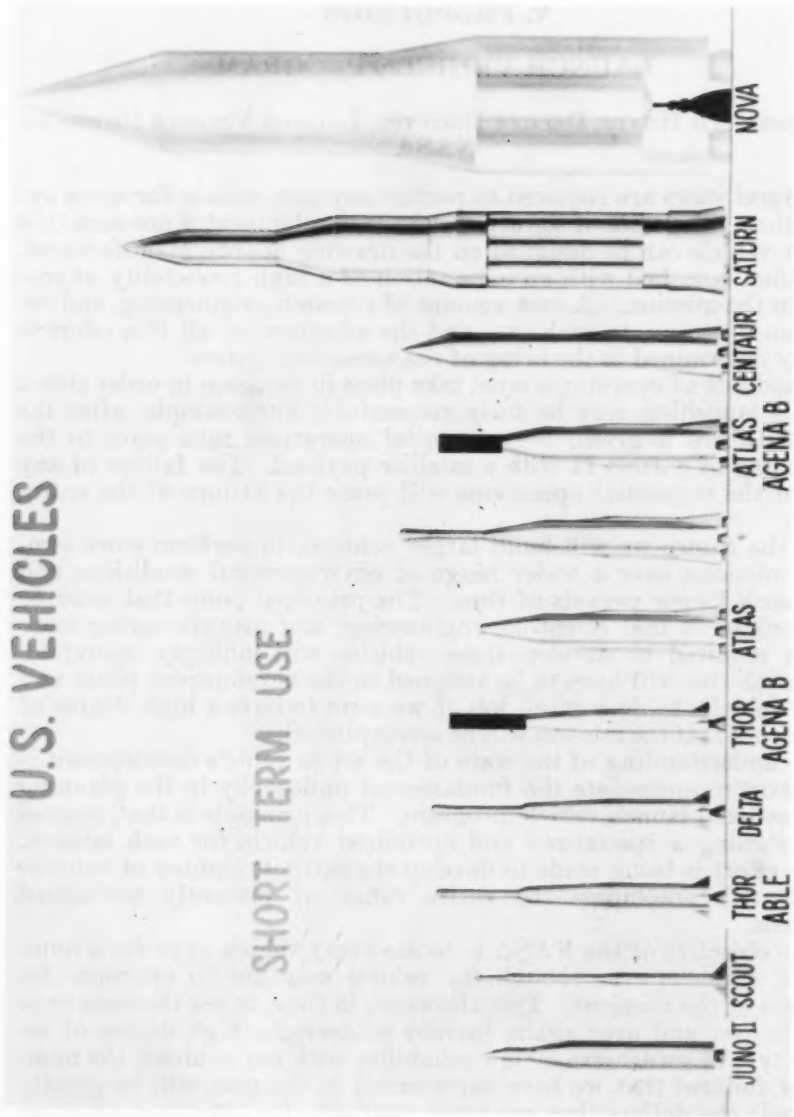

U.S. VEHICLES
SHORT TERM USE
JUNO II
SCOUT
THOR ABLE
DELTA
THOR AGENA B
ATLAS
ATLAS AGENA B
CENTAUR
SATURN
NOVA

FIGURE 113

SCOUT

The Scout is a four-stage solid propellant vehicle (figs. 114 and 115). It was initiated in late 1958 and is making very good progress. Every one of the four motors has been fired. The guidance system for it is now being assembled and assembly of the entire vehicle is now in progress. A first launching is expected in mid-1960. The vehicle is expected to have a multiplicity of uses. As much as 200 pounds can be placed into a 300-nautical mile altitude orbit above the earth with Scout. Vertical probes, with useful payloads, to an altitude as much as 4,000 miles, can be accomplished. In addition, it can be used for all kinds of advanced testing, within the atmosphere, of very high speed airframe designs and reentry bodies.

One of the principal merits of the Scout is its low cost. The cost of production vehicles, plus the cost of the launching operation, may be as low as $700,000. In comparison, to buy and launch a Delta may cost as much as $3½ million.

THOR-ABLE

The Thor-Able consists of the Thor IRBM as the first stage, a Vanguard second stage as the next stage, and a third stage which was developed initially for Vanguard. This vehicle has been used in four space mission attempts. Of these, only one firing has been fully successful. Two additional launchings with this vehicle are scheduled.

DELTA

The Delta vehicle was initiated early in 1959 (figs. 116 and 117). A total of 12 are on order. It utilizes hardware similar to that employed in Thor-Able but with a number of reliability and performance improvements. Portions of the second and third stage have been simplified and ruggedized. A highly accurate guidance system adapted from the Titan program has been added. The progress in the development of this vehicle is good. NASA hopes to launch the first of this series in mid-1960. No reorders of Delta vehicles are planned.

JUNO II

The Army developed Juno II. It is made up of the Jupiter IRBM as the first stage, and clustered solid rocket motors for the upper stages. The causes of two successive failures with the Juno II last summer have been isolated and corrected. Four additional Juno II's are scheduled for firing during calendar year 1960. After this program is completed, the Juno II is phased out of the NASA vehicle program.

THOR-AGENA B

The Thor-Agena B consists of a Thor IRBM first stage and a second stage which is a modified and enlarged version of the second stage that has been used very successfully in the Discoverer program (figs. 118 and 119). Because of the high reliability for putting payloads into orbit that has been obtained with the Discoverer program, the NASA has decided to employ the Thor-Agena B as a successor to the previous IRBM-based space vehicles such as Thor-Able, Delta, and

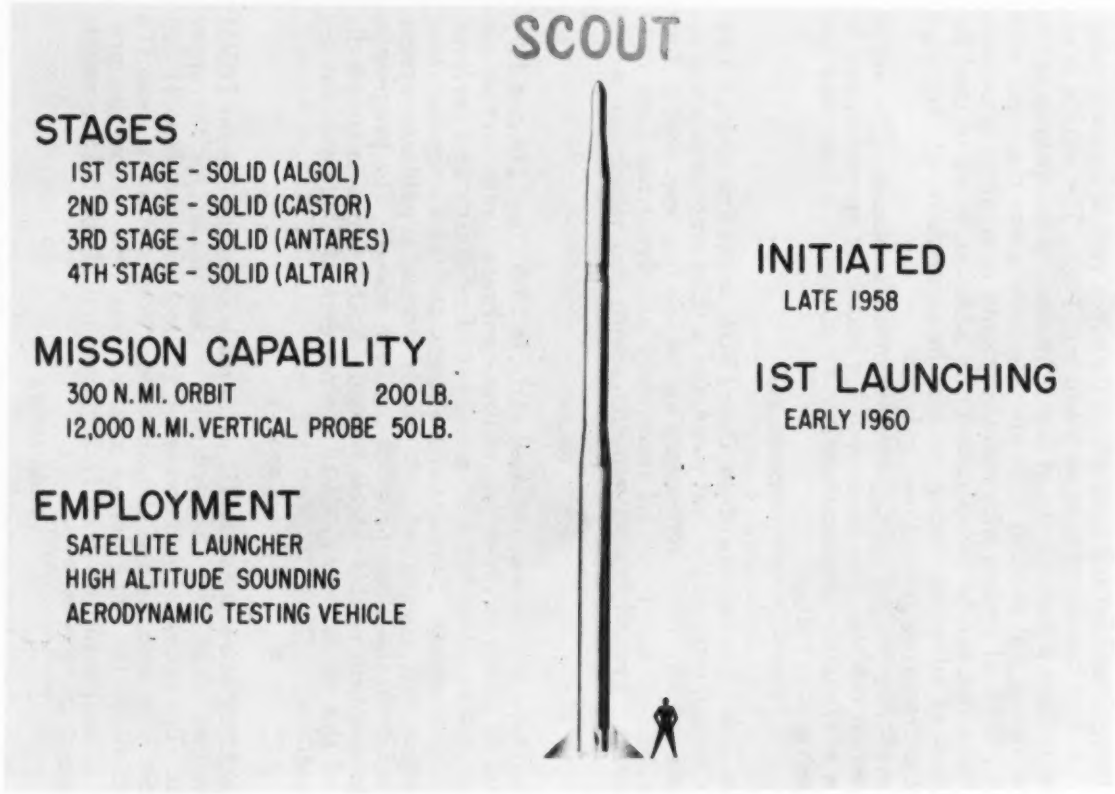


FIGURE 114

SCOUT

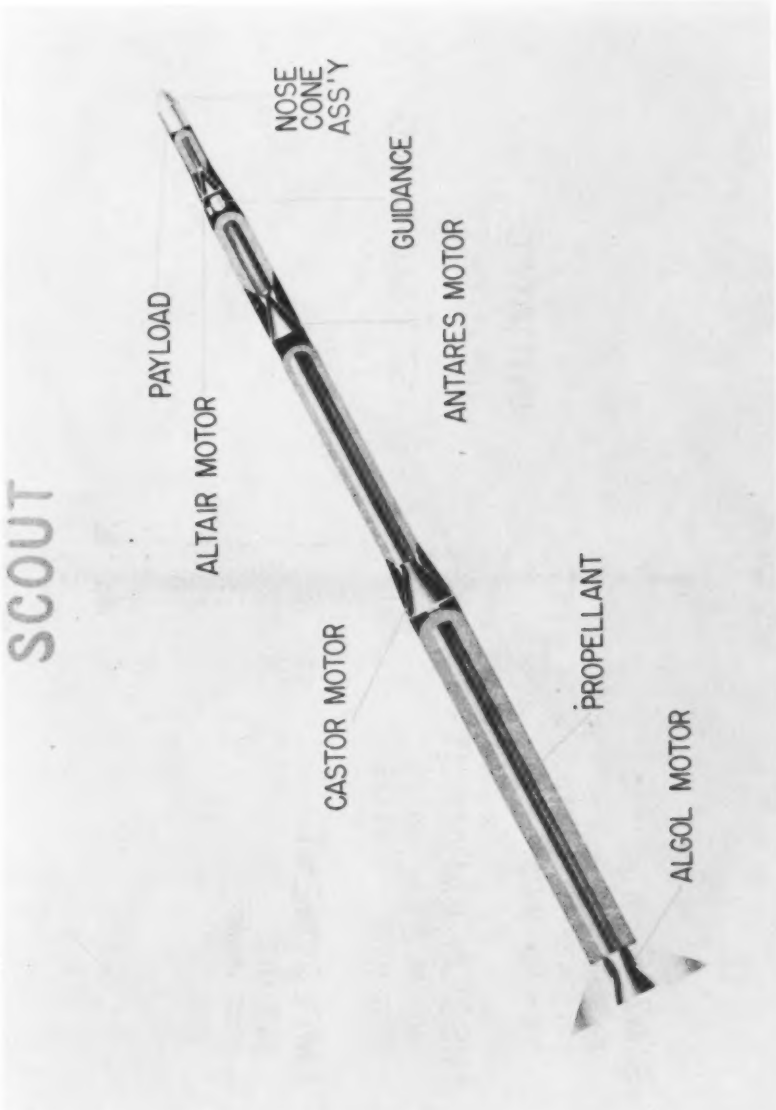

SCOUT
PAYLOAD
ALTAIR MOTOR
CASTOR MOTOR
PROPELLANT
ALGOL MOTOR
NOSE CONE ASS'Y
GUIDANCE
ANTARES MOTOR

FIGURE 115

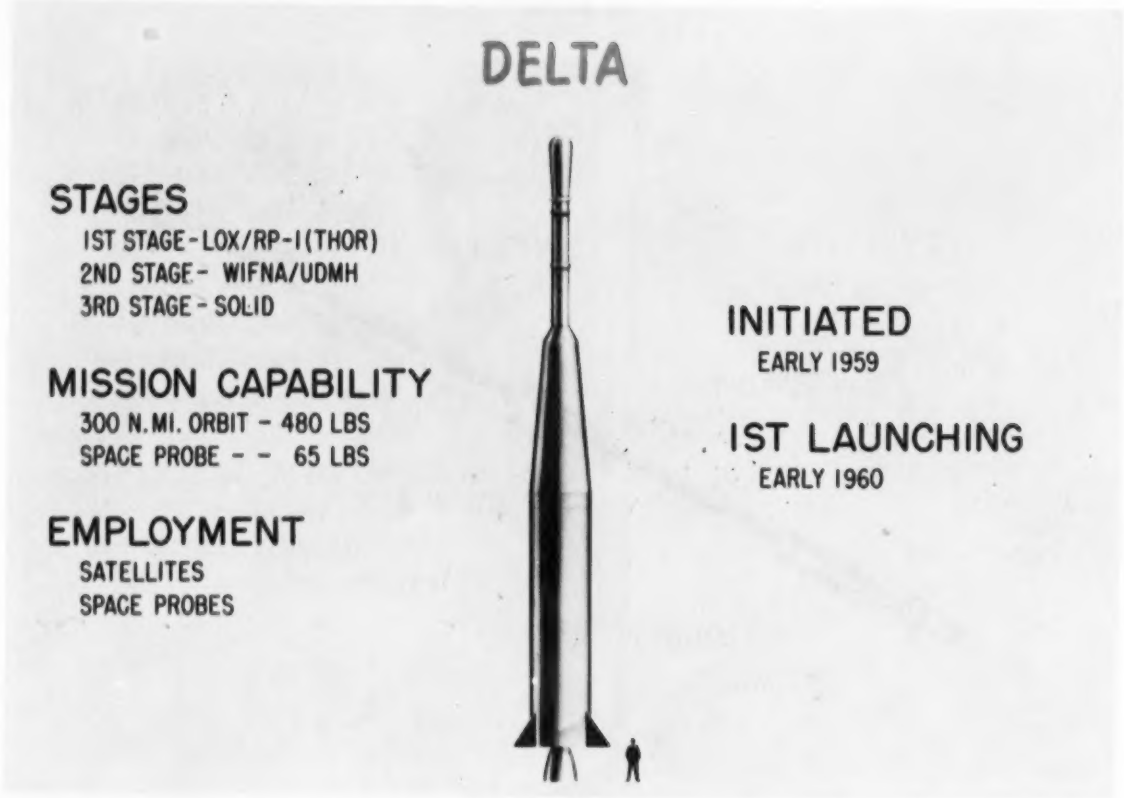

DELTA
STAGES
1ST STAGE - LOX/RP-1 (THOR)
2ND STAGE - WIFNA/UDMH
3RD STAGE - SOLID
MISSION CAPABILITY
300 N. MI. ORBIT - 480 LBS
SPACE PROBE - - 65 LBS
EMPLOYMENT
SATELLITES
SPACE PROBES
INITIATED
EARLY 1959
1ST LAUNCHING
EARLY 1960

FIGURE 116

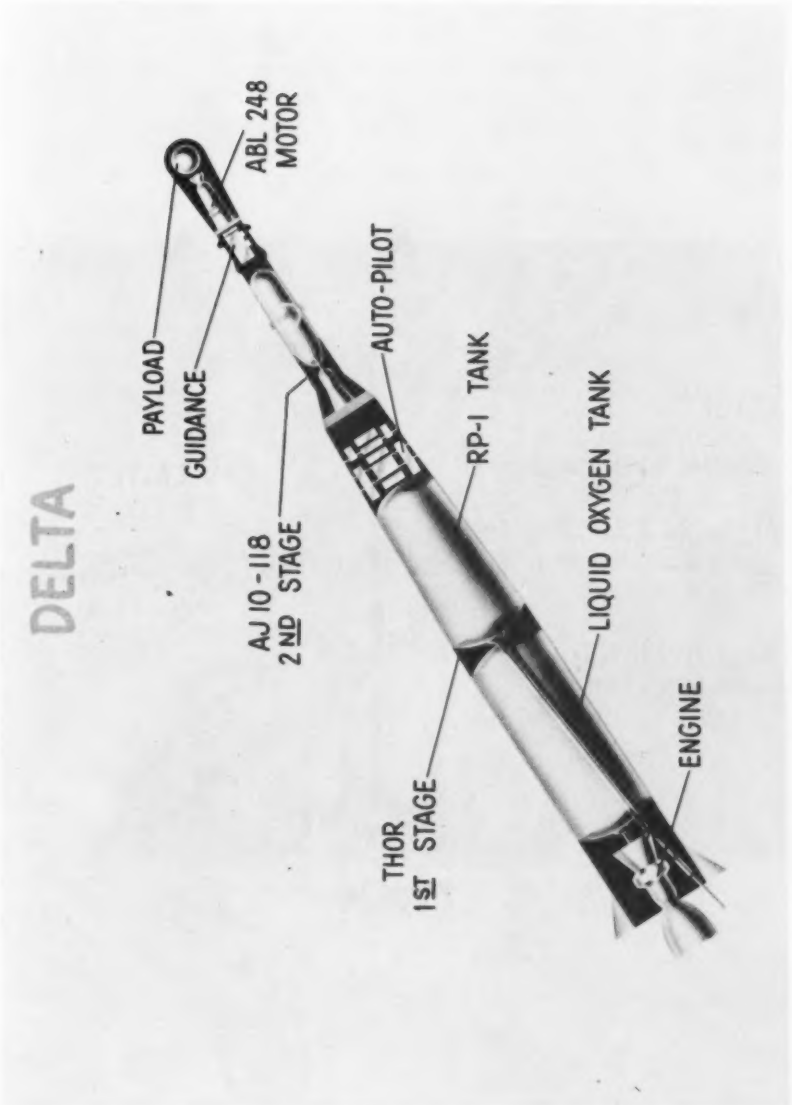

DELTA
PAYLOAD
GUIDANCE
ABL 248
MOTOR
AUTO-PILOT
RP-1 TANK
LIQUID OXYGEN TANK
ENGINE
AJ 10-118
2ND STAGE
THOR
1ST STAGE

FIGURE 117

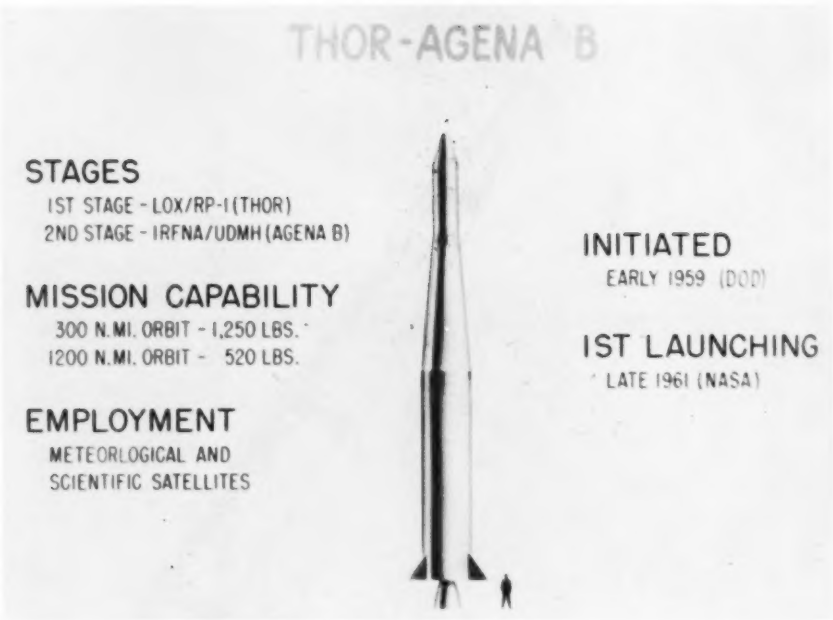

THOR-AGENA B
STAGES
1ST STAGE - LOX/RP-1 (THOR)
2ND STAGE - IRFNA/UDMH (AGENA B)
MISSION CAPABILITY
300 N.MI. ORBIT - 1,250 LBS.
1200 N.MI. ORBIT - 520 LBS.
EMPLOYMENT
METEORLOGICAL AND
SCIENTIFIC SATELLITES
INITIATED
EARLY 1959 (DOD)
1ST LAUNCHING
LATE 1961 (NASA)

FIGURE 118

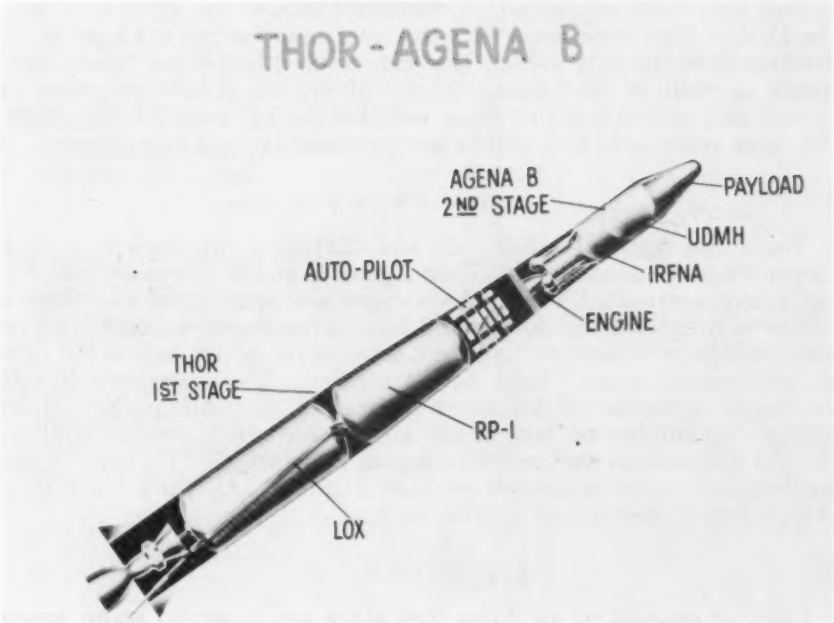

THOR-AGENA B
AGENA B
2ND STAGE
PAYLOAD
UDMH
IRFNA
AUTO-PILOT
ENGINE
THOR
1ST STAGE
RP-1
LOX

FIGURE 119

Juno II. It is planned to use the Thor-Agena B for such missions as scientific satellites, meteorological satellites, and other space missions which require medium weight payloads.

ATLAS

The next vehicle shown on figure 113 (p. 778) is the basic Atlas ICBM with some relatively small modifications. Present plans are that this booster will be used only in the Mercury program. By the time it is used to launch a manned capsule around the Earth, it will have had a great many firings and should have attained a high degree of reliability.

ATLAS-ABLE

This vehicle consists of a modified Atlas ICBM as a first stage, and second and third stages very similar to those of the Thor-Able and the Delta. Our experience with this vehicle so far has not been good. Because it is the only vehicle that can be used to place a barely adequate payload in the vicinity of the Moon, the NASA proposes to launch one or two more of these vehicles during calendar year 1960. No more vehicles of this nature are proposed beyond this period.

ATLAS-AGENA B

The Atlas-Agena B (figs. 120 and 121) uses the same improved upper stage planned for the Thor-Agena B and is a replacement for the recently canceled Vega. Two stages are used in place of Vega's three—a simplification that should lead to increased reliability. The basic design will have undergone a number of firings before the first Atlas-Agena B is used for a NASA mission. This same vehicle will be used in a number of Air Force programs. Common usage will increase the number of launchings and so lead to higher reliability. NASA proposes to use the Atlas-Agena B principally for early lunar exploration—close approach or hard landing. In time the Atlas-Agena B may be replaced by the Centaur.

CENTAUR

Centaur consists of an Atlas first stage and a second stage which uses hydrogen and oxygen as propellants (figs. 122 and 123). It is the most advanced upper stage planned for Atlas and has the greatest capability of any Atlas-boosted vehicle. The engineering design of the engine is complete. Several experimental engines have been built and are now undergoing developmental testing. One engine has been operated for more than 10 minutes at full thrust. The engineering design of the stage itself is also rapidly nearing completion. The inertial guidance system for this vehicle has many advanced features and we have a high degree of confidence in its successful development. A great deal of research, engineering, and developmental testing yet remains to be done before the first launching attempt. All in all, the progress of this vehicle may be considered satisfactory.

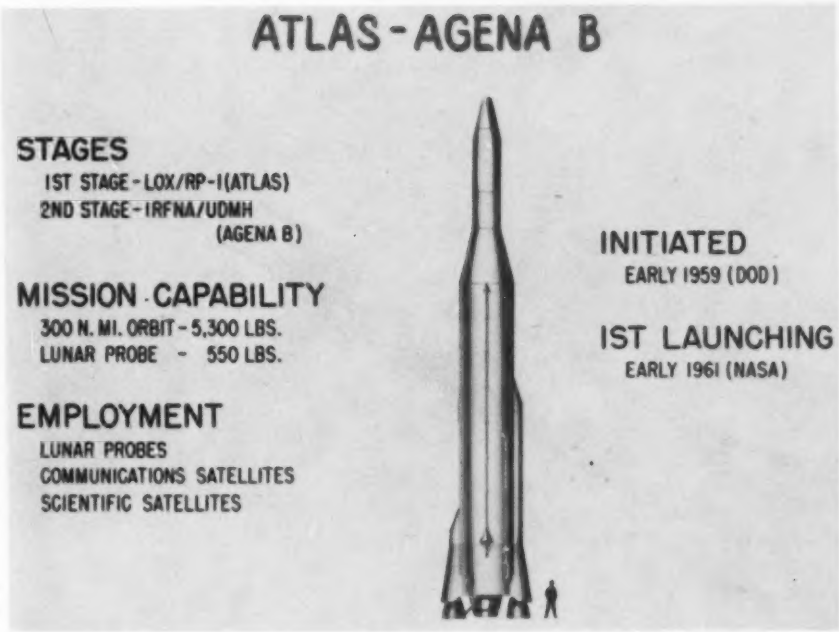

ATLAS - AGENA B
STAGES
1ST STAGE - LOX/RP-1(ATLAS)
2ND STAGE - IRFNA/UDMH
(AGENA B)
MISSION CAPABILITY
300 N. MI. ORBIT - 5,300 LBS.
LUNAR PROBE - 550 LBS.
EMPLOYMENT
LUNAR PROBES
COMMUNICATIONS SATELLITES
SCIENTIFIC SATELLITES
INITIATED
EARLY 1959 (DOD)
1ST LAUNCHING
EARLY 1961 (NASA)

FIGURE 120

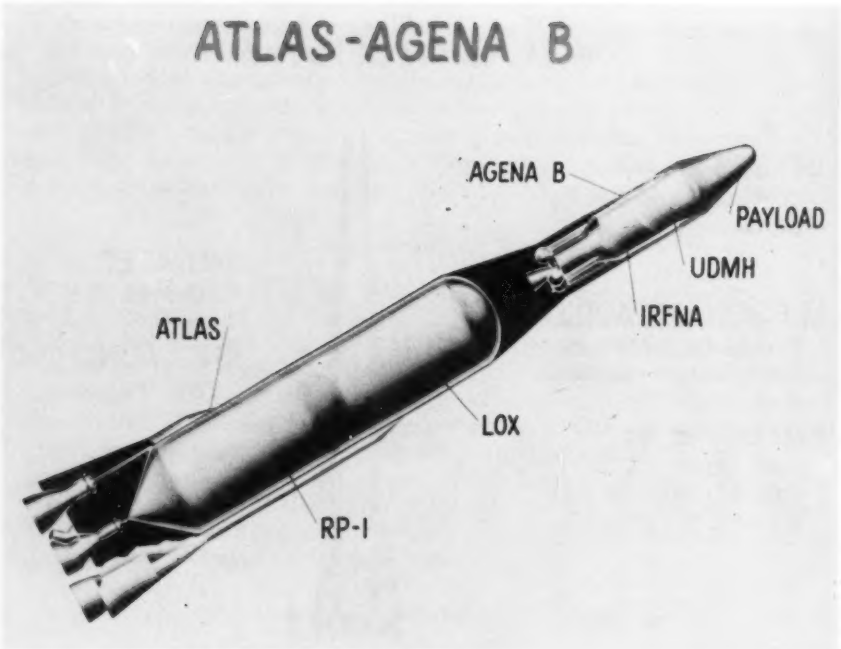


FIGURE 121

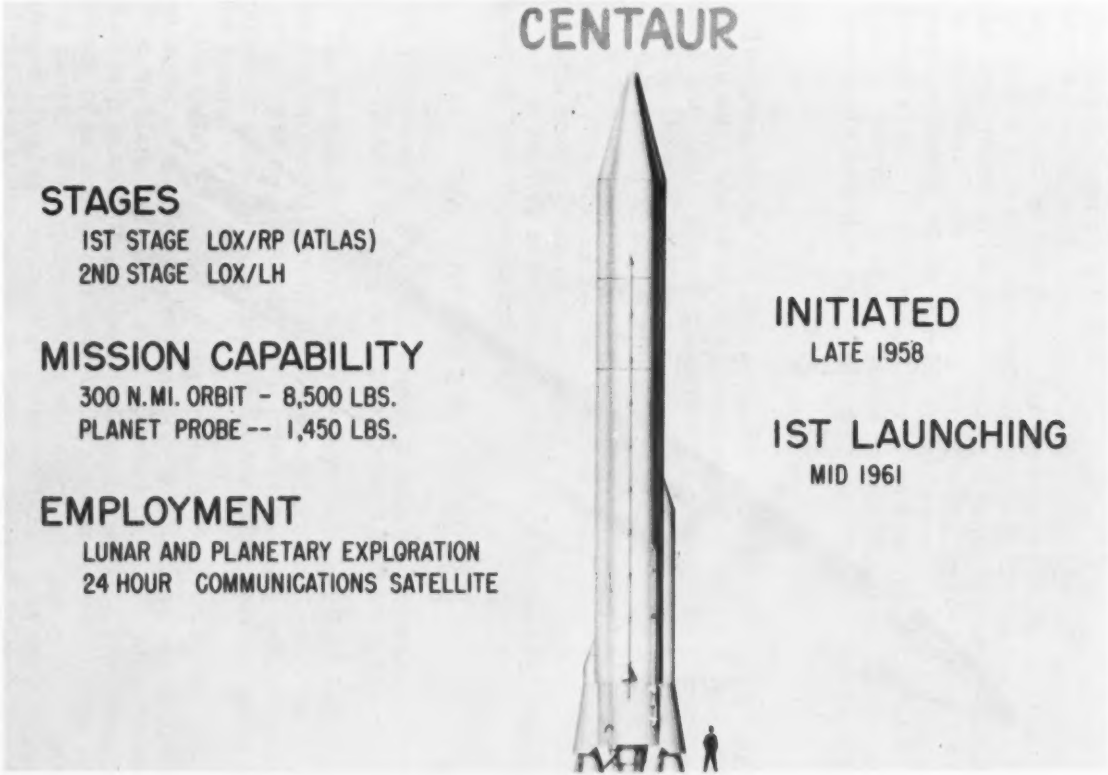

CENTAUR
STAGES
1ST STAGE LOX/RP (ATLAS)
2ND STAGE LOX/LH
MISSION CAPABILITY
300 N.MI. ORBIT - 8,500 LBS.
PLANET PROBE -- 1,450 LBS.
EMPLOYMENT
LUNAR AND PLANETARY EXPLORATION
24 HOUR COMMUNICATIONS SATELLITE
INITIATED
LATE 1958
1ST LAUNCHING
MID 1961

FIGURE 122

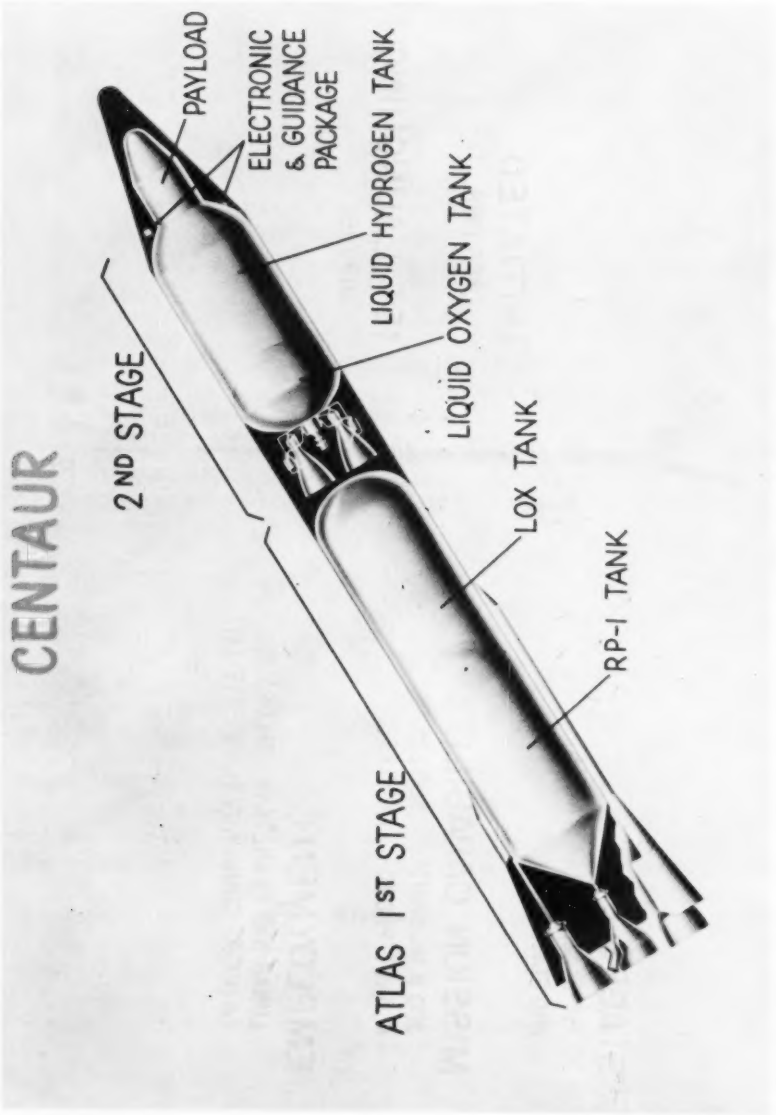

CENTAUR
2 ND STAGE
ATLAS 1 ST STAGE
PAYLOAD
ELECTRONIC & GUIDANCE PACKAGE
LIQUID HYDROGEN TANK
LIQUID OXYGEN TANK
LOX TANK
RP-1 TANK

FIGURE 123

SATURN

Saturn is the highest capability launch vehicle being developed in the United States (figs. 124 and 125). Its first stage, in development by the ABMA at Huntsville, achieves a thrust of over 1 million pounds by clustering 8 ICBM-type engines. The engineering design of this stage is well along. Static firing tests of the first stage were begun in April of this year. The configurations of the upper stages for Saturn have now been determined and a contract has been let for the development of the second stage. The third stage of Saturn will be a modified Centaur second stage. Saturn is expected to be a multipurpose launch vehicle for advanced space missions in the period beyond 1963. It will launch very large satellites, of about 10 to 20 tons in weight. With it, sizable payloads can be landed on the Moon and substantial payloads sent to the vicinity of Mars and Venus.

NOVA

The name "Nova" has been applied to a purely analytical design of a vehicle using the 1,500,000-pound-thrust engine now under development (fig. 126). The mathematical analysis of this design has been done by the staff at NASA headquarters. No preliminary or engineering design on such a vehicle is now being supported by NASA. Nova is a design concept for the largest rocket vehicle being considered by the United States. Its thrust level, not yet decided, may be in the multimillion-pounds class.

In time we hope to reduce the number of vehicles in the space programs to those shown in figure 127.

SPACE PROPULSION

By Wolfgang E. Moeckel, Chief, Advanced Propulsion Division, NASA Lewis Research Center, Cleveland, Ohio

The potentialities and research problems associated with electric propulsion systems are of great interest because these systems have a capability of reducing fairly well-provisioned and well-manned interplanetary expeditions to sizes which are fairly reasonable for use in the future.

One example of this is shown in figure 128. We have made some estimates of the weights required for launching an eight-man expedition to Mars. We have the weight we have to put into orbit around the Earth in order to get these missions underway. This mission will consist of launching and assembling a space vehicle in orbit around the Earth. This space vehicle will then take the crew to an orbit around Mars, and an auxiliary craft will then land the crew or part of the crew on the surface of Mars for an exploration lasting up to several months. Then a takeoff rocket will take the crew from the surface of Mars back to the space vehicle, and that vehicle will bring them back to an orbit around the Earth.

These are the weights that the space vehicle has to start with in orbit around the Earth in order to complete this expedition. If we try to do it with even high-energy chemical rockets, we would have to launch about 2.4 million pounds into orbit to get the expedition

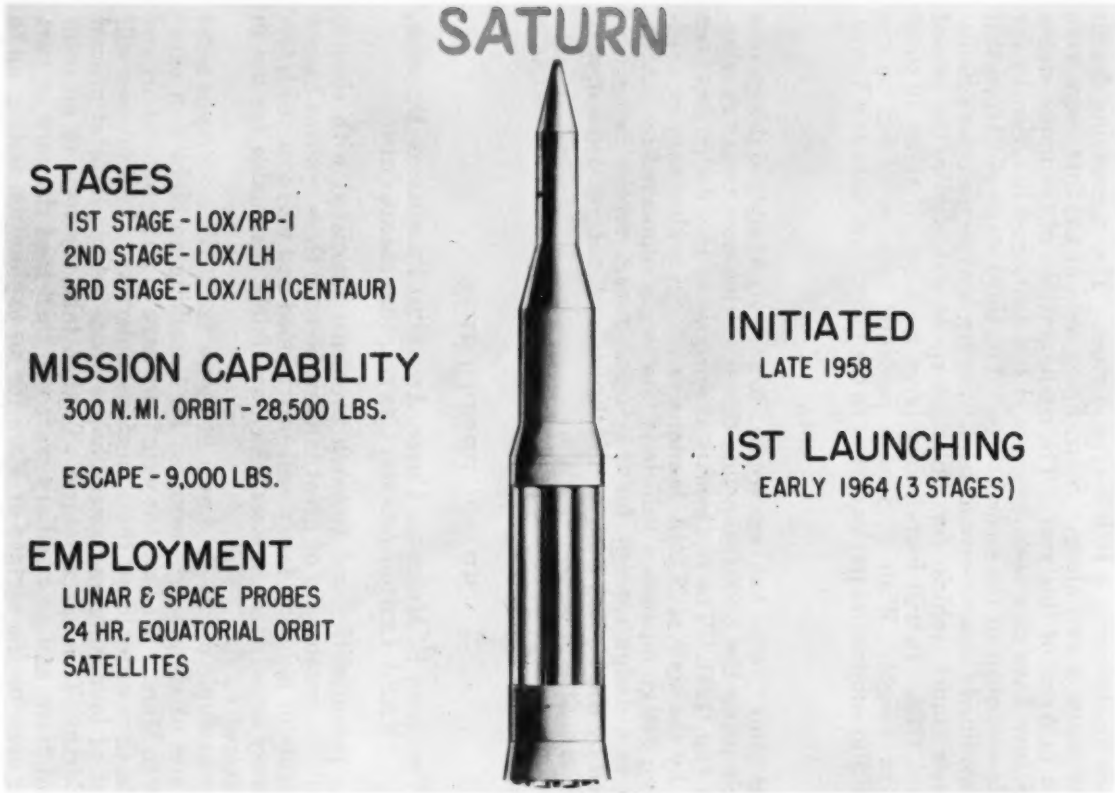

SATURN
STAGES
1ST STAGE - LOX/RP-1
2ND STAGE - LOX/LH
3RD STAGE - LOX/LH (CENTAUR)
MISSION CAPABILITY
300 N. MI. ORBIT - 28,500 LBS.
ESCAPE - 9,000 LBS.
EMPLOYMENT
LUNAR & SPACE PROBES
24 HR. EQUATORIAL ORBIT
SATELLITES
INITIATED
LATE 1958
1ST LAUNCHING
EARLY 1964 (3 STAGES)

FIGURE 124

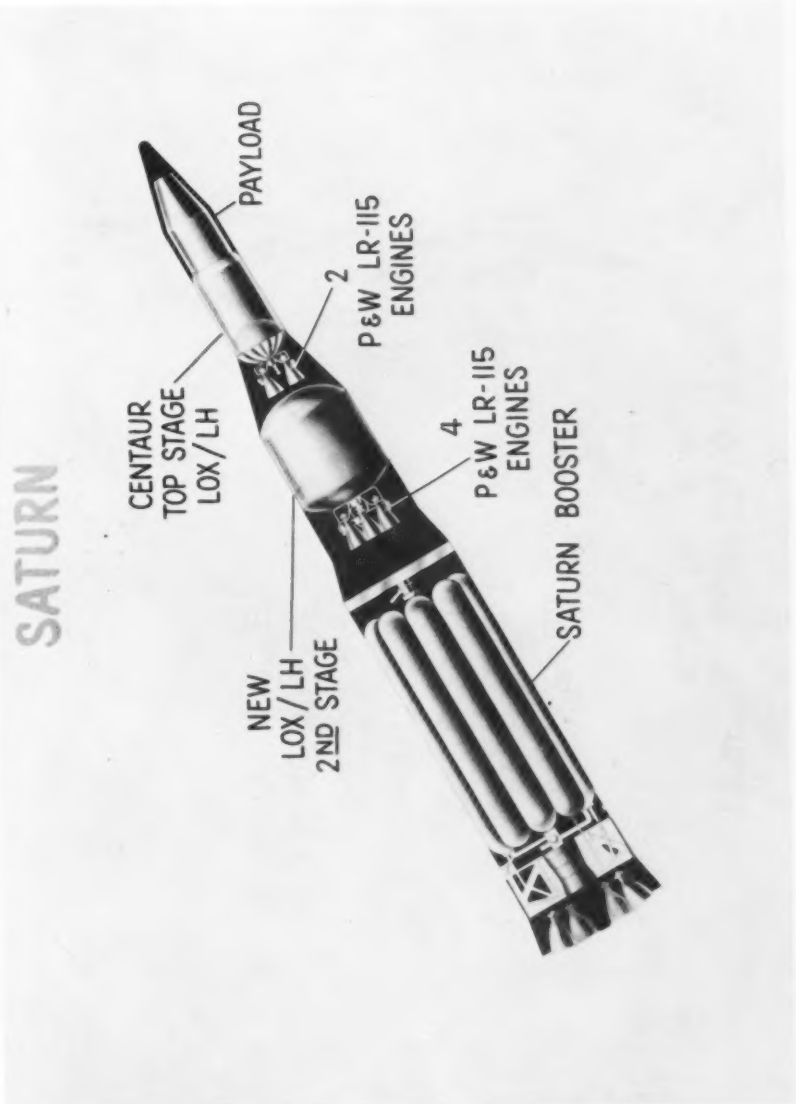

SATURN
PAYLOAD
2
P&W LR-115
ENGINES
CENTAUR
TOP STAGE
LOX/LH
4
P&W LR-115
ENGINES
NEW
LOX/LH
2ND STAGE
SATURN BOOSTER

FIGURE 125

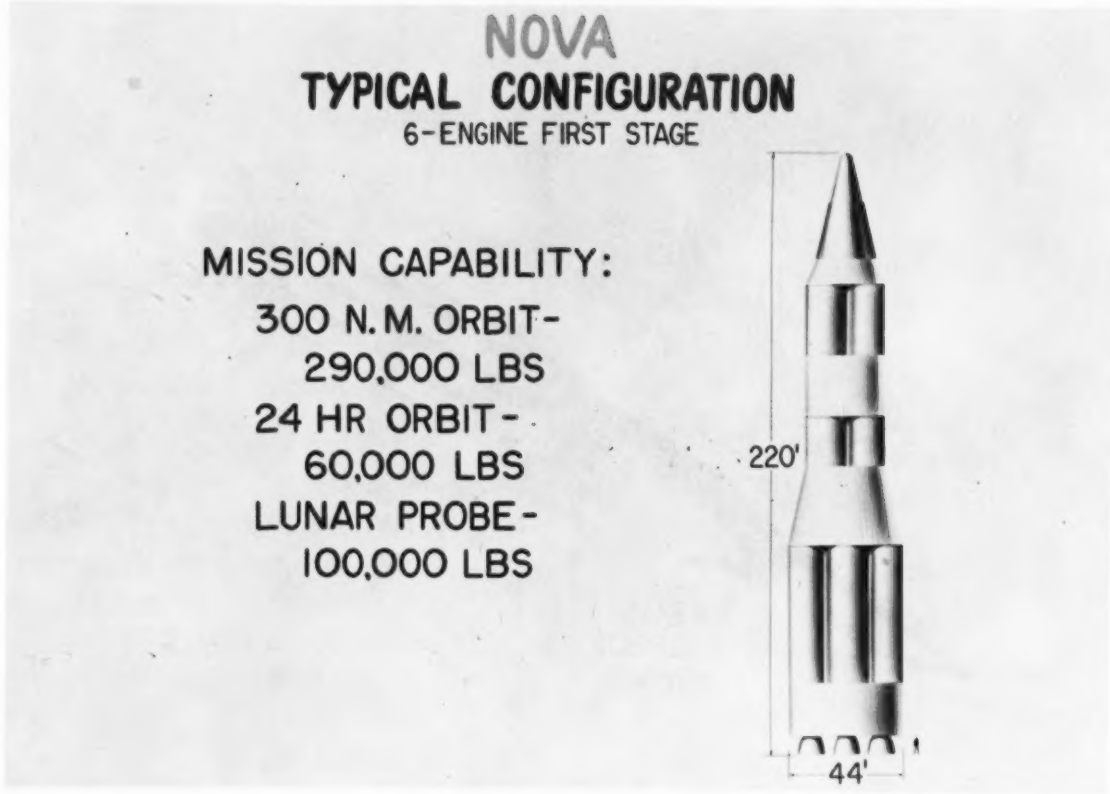

NOVA
TYPICAL CONFIGURATION
6-ENGINE FIRST STAGE
MISSION CAPABILITY:
300 N. M. ORBIT-
290,000 LBS
24 HR ORBIT-
60,000 LBS
LUNAR PROBE-
100,000 LBS
220'
44'

FIGURE 126

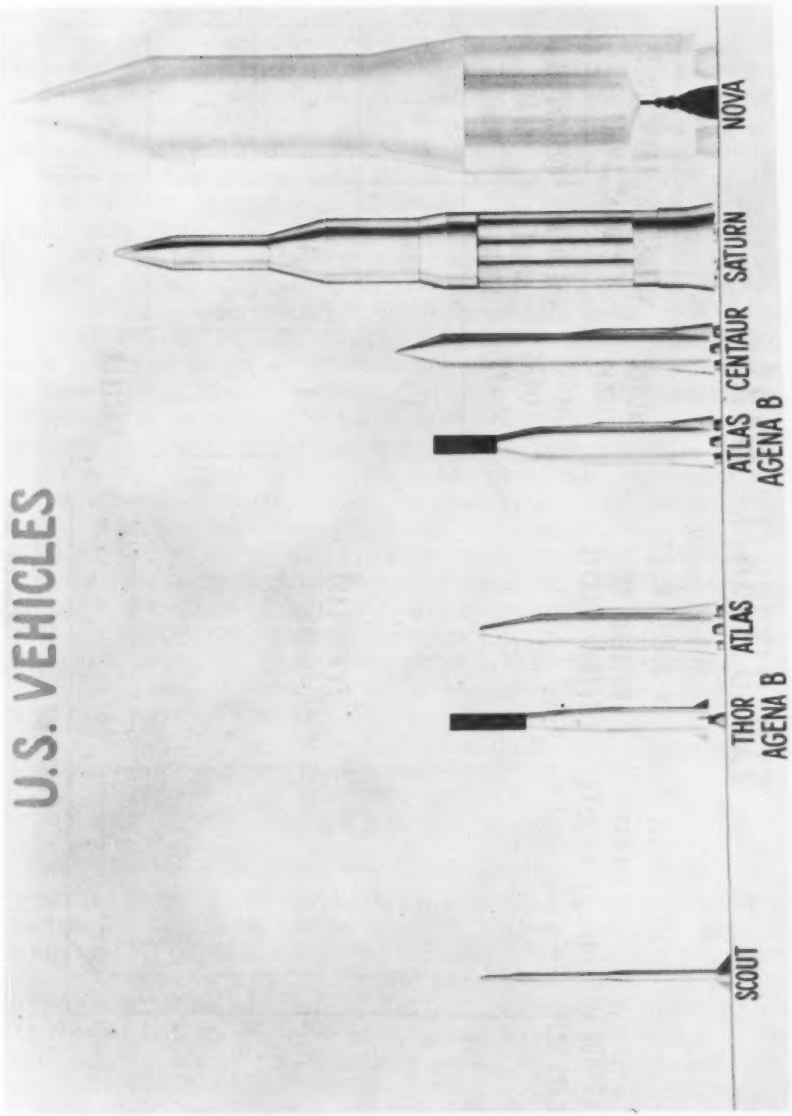
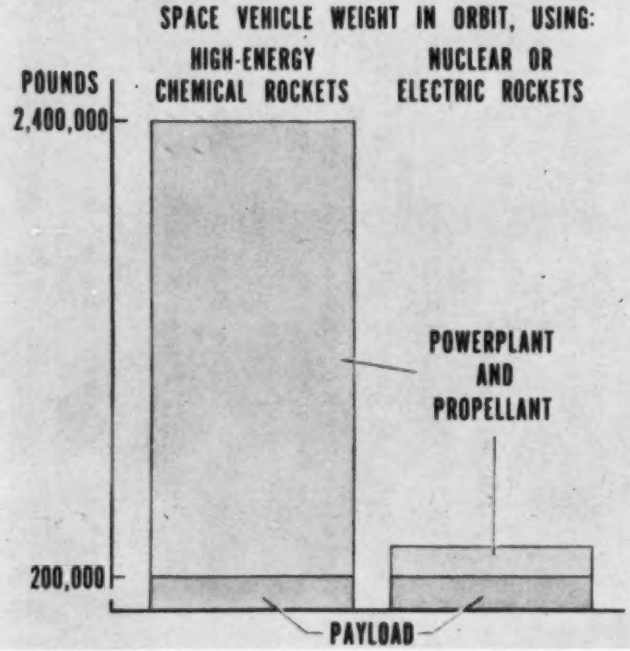

U.S. VEHICLES
SCOUT
THOR
AGENA B
ATLAS
ATLAS
AGENA B
CENTAUR
SATURN
NOVA

FIGURE 127

REQUIREMENTS FOR LAUNCHING 8-MAN EXPEDITION TO MARS



LAUNCH ROCKET THRUST MILLIONS OF LBS	NUMBER OF LAUNCHINGS TO ASSEMBLE	
	CHEMICAL SPACE VEHICLE	NON-CHEMICAL SPACE VEHICLE
1.5	100	16
6	24	4
24	6	1
NUCLEAR: 6	6	1

FIGURE 128

started. Of this, only about 200,000 pounds is initial payload weight. The rest is nearly all propellant.

NONCHEMICAL PROPULSION SYSTEMS

If we consider the nonchemical propulsion systems, namely, nuclear rockets and electric rockets, we find that we might be able to do this entire mission by launching only about 400,000 pounds into orbit, a rather tremendous reduction indeed. This is with the same 200,000-pound payload, but now the powerplant plus propellent weight has been reduced to only about 200,000 pounds.

The right half of the chart shows the launching requirements to get these vehicles into orbit. If we use the 1½-million-pound-thrust booster rockets which are now under development by NASA, we find that to get this chemically powered space vehicle into orbit we would have to launch 100 of these 1½-million-pound boosters. If we launched the nonchemical space vehicle into orbit, this number is reduced to only 16. In addition, if we can cluster 4 of these, as is now planned, to get a 6-million-pound thrust for boosting from the surface of the Earth, we would still require 24 of these tremendous boosters for launching the chemical space vehicle into orbit; only about 4 are required for the nonchemical space vehicle. Assembling these many parts into a single, orbiting vehicle represents a rather tremendous technical problem in rendezvous, and perhaps an even more severe problem is paying for all the boosters required.

If we can go a step further and boost the thrust of the launching rockets to something like 24 million pounds, we find that we could launch the entire nonchemical space vehicle with a single launching; and we would not have to worry about rendezvous and assembly problems in space. This is the potential of the nonchemical system.

These electric rockets are not only useful for the fairly advanced and high-payload missions. That is the chief justification for developing them, but if we have them we can also make very good use of them for more prosaic missions in the next few years.

ELECTRIC PROPULSION SYSTEMS

The electric rockets are characterized by the fact that they can generate only a very small thrust, but they also can generate that thrust for very long periods of time with very low propellant consumption. This means that electric rockets are ideal for those missions requiring a little bit of thrust for long periods of time. The control of the orientation and orbit of Earth satellites is one such application. If the satellite must point in the same direction for long periods of time, and be stabilized on a given orbit, the electric rockets are ideal for such applications.

For instrumented space probes, chemical rockets are now being developed which will be able to undertake Mars and Venus probe missions with quite reasonable scientific payloads. If we go to electric rockets, though, we find we can carry more payload on these missions for the same initial weight; and as we go closer to the Sun than Venus or farther out than Jupiter, the weight advantage of the electric propulsion method becomes ever greater. The reason electric propul-

sion has these advantages is that we can eject the propellants out the back end at much higher velocity. The higher the velocity with which we can throw the propellant out backward, the less propellant we need for the same mission capability.

NUCLEAR TURBOELECTRIC SYSTEM

Figure 129 shows some of the principles of the nuclear turboelectric propulsion system. The nuclear reactor is the basic energy source. A pump circulates fluid through a reactor to pick up the heat; the fluid is then vaporized, and the resulting vapor drives the turbine which drives the generator which provides electric power to accelerate the propellant out with very high velocities. The vapor which comes out of the turbine is condensed in quite a large radiator in order to get rid of the waste heat. The condensate then goes back through the reactor to pick up more heat. This complete system is very elaborate, and the only justification for it is that we can get very high jet velocities.

Chemical rockets are limited by the fact that chemical reactions basically do not have very much energy. With nuclear rockets we are not limited energywise, but we are limited by material temperature. We cannot get this propellant up to higher temperatures than the materials of the nuclear rocket will stand.

With the electric rocket we are limited in neither way. We can put in all the energy we want, and we are not limited by material temperature, and the reason is this: If we heat the gas or the propellants by electric means, we find that we can use electric fields and magnetic fields to keep the hot gases away from the wall, thereby avoiding the heat transfer problem or the high temperature problem. If we do have electric power, though, we do not really have to heat the gas very hot, because high temperature is only one way in which we can get very high jet velocities and, therefore, low propellant consumption. If we can ionize the propellants as they come out, that is, strip off an electron and make charged particles of them, then we can accelerate them to almost any speed we want to by putting sufficient voltage on them. Charged particles can be accelerated very easily with sufficiently high voltage.

WEIGHT PROBLEM

The limitation now arises in the weight of all this propulsion system. If this system weighs more than the propellants we save, of course we are no better off than in using chemical rockets. So the idea is to get the propulsion system weight down as low as possible. To do this, we might use other basic energy sources. The nuclear turboelectric type seems to be the most promising from the standpoint of light weight for very large power output, and using this type, jet velocities of the order of 200,000 miles per hour are possible. The chemical rocket yields jet velocities of about 10,000 miles per hour; the nuclear rocket 25,000. The best jet velocity here is around 200,000 miles per hour, a factor of over 8 over the nuclear rocket, and about 20 over the chemical rocket.

Thus the weight estimate we have made of the rest of the propulsion system indicates that overall this will weigh much less than the chemical rocket, and moderately less than the nuclear rocket for the

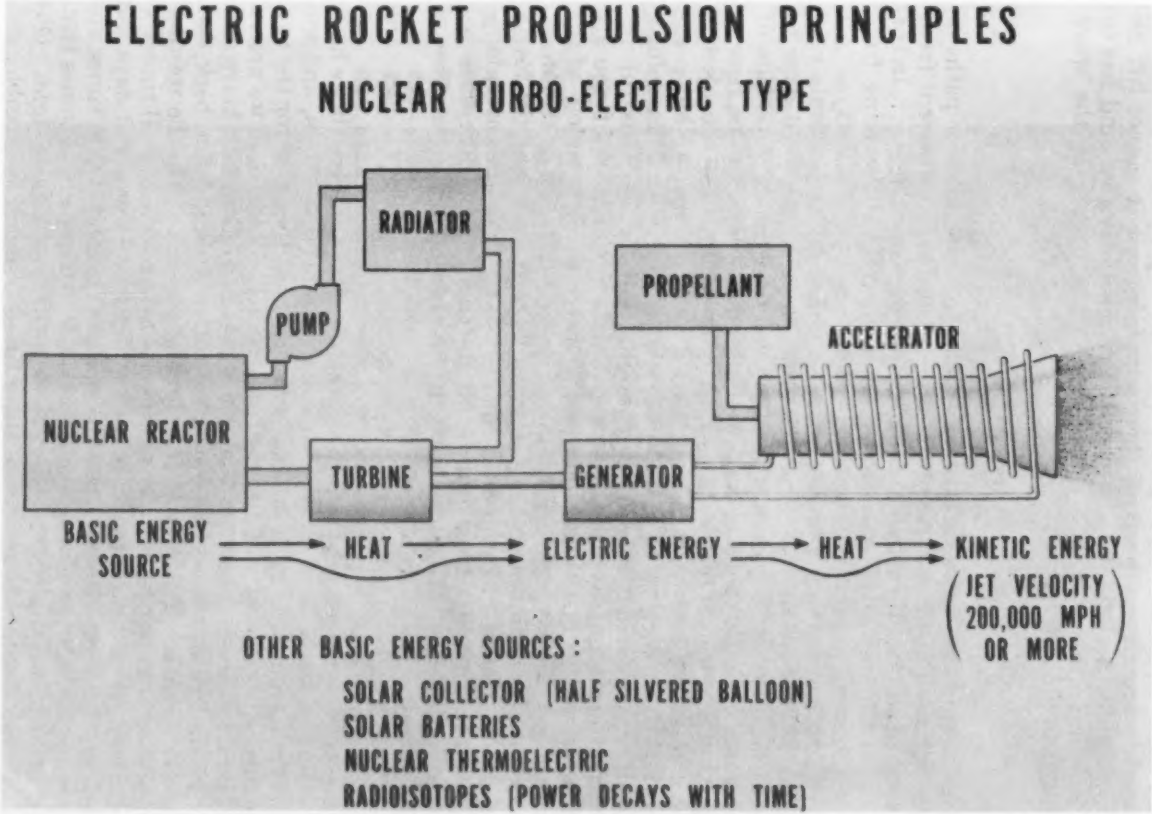

ELECTRIC ROCKET PROPULSION PRINCIPLES
NUCLEAR TURBO-ELECTRIC TYPE
RADIATOR
PUMP
PROPELLANT
ACCELERATOR
NUCLEAR REACTOR
TURBINE
GENERATOR
BASIC ENERGY SOURCE
HEAT
ELECTRIC ENERGY
HEAT
KINETIC ENERGY
(JET VELOCITY 200,000 MPH OR MORE)
OTHER BASIC ENERGY SOURCES :
SOLAR COLLECTOR (HALF SILVERED BALLOON)
SOLAR BATTERIES
NUCLEAR THERMOELECTRIC
RADIOISOTOPES (POWER DECAYS WITH TIME)

FIGURE 129

same mission. Due to the high weight of the powerplant required to generate the electric power, we find that we cannot develop much thrust. We get a thrust which is much lower than the weight of all the equipment. That means that electric propulsion will never be used to launch anything off the ground, because it cannot lift its own weight. So it is strictly a space propulsion system, and has to be launched into orbit, and from there it can undertake the space missions to the other planets.

SPACE MISSIONS

Due to this low thrust, it turns out that the trajectories or paths in space followed using electric propulsion are quite a bit different from those used in high-thrust rockets such as chemical or nuclear. In the case of the high-thrust rocket we follow a curved path starting from the Earth, and get out to the orbit of the Moon in about 2 days. An electric rocket starting from an orbit around the Earth spirals very gradually because of its low thrust, and it takes about 50 days to reach the orbit of the Moon (fig. 130). This is using 2 pounds of thrust for each 10,000 pounds of weight, which we find to be reasonable for the weight estimates which were made. So the electric rocket does not look particularly attractive for a man-to-Moon expedition if it is going to take 50 days compared with 2 days for a high-thrust system. However, it might still be very useful for transferring large payloads from the Earth to the Moon if you are not interested in fast times, but you are interested in economy of the operation. If we continue accelerating beyond the orbit of the Moon, we eventually acquire enough energy to leave the orbit of the Earth and go on toward the orbit of Venus or Mars. For the interplanetary trips, the times look quite a bit different. The difference between high-thrust and low-thrust propulsion systems timewise is not as great.

MARS EXPEDITION

The reason is that, for both cases, when we leave the Earth we have to follow a fairly long coast path out to the orbit of Mars, and the coast time from the Earth to Mars' orbit is about the same for the two systems, a low-thrust and a high-thrust rocket. Also, once we arrive at Mars we have to wait quite long periods of time before Mars and the Earth are in the right position so that we could come back and catch the Earth when it is at the right place, and again the waiting times are about the same for the two systems. So the overall time for the whole round trip mission is not too much different: 973 days for the high thrust and about 1,060 for the low thrust. These times are for what we call the most economical paths. They are the ones that permit us to accomplish the mission with the least total weight. Obviously we would like to reduce these times as much as possible, and our preliminary estimates indicate that with electric propulsion we should be able to reduce 1,000 days to about 600 days, with rather moderate increases in the initial weight for the mission (fig. 131).

ESCAPE TRAJECTORIES WITH LOW-THRUST PROPULSION SYSTEM

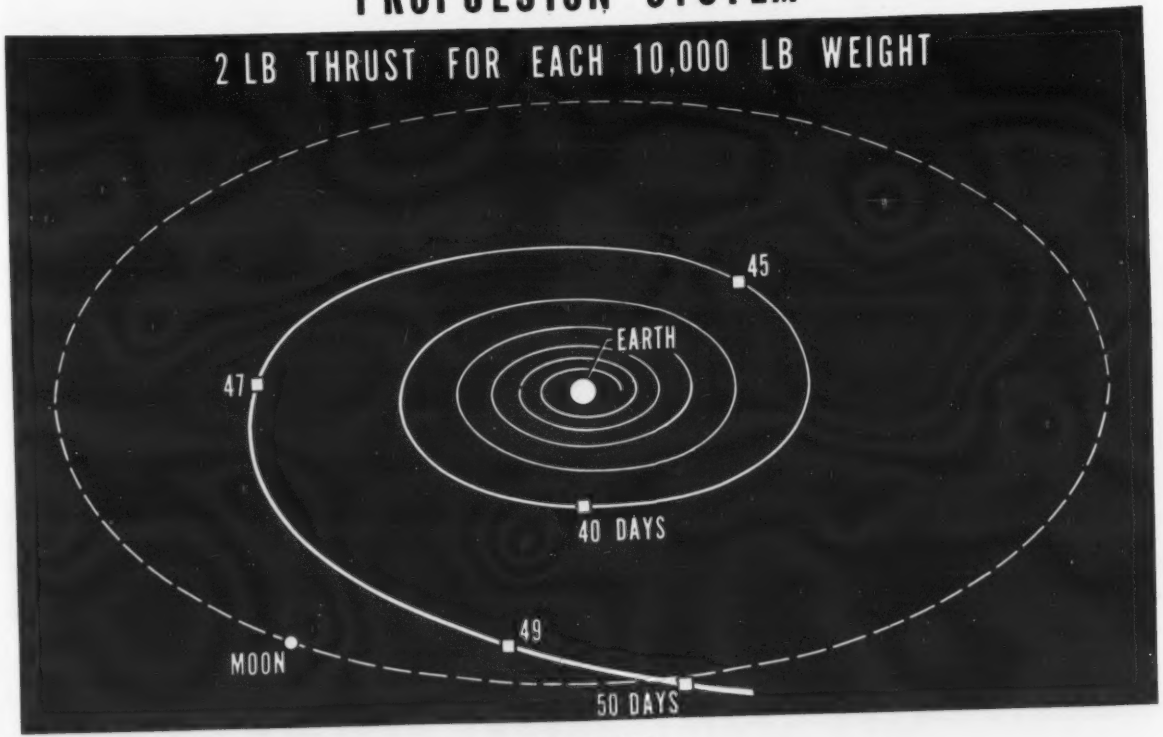
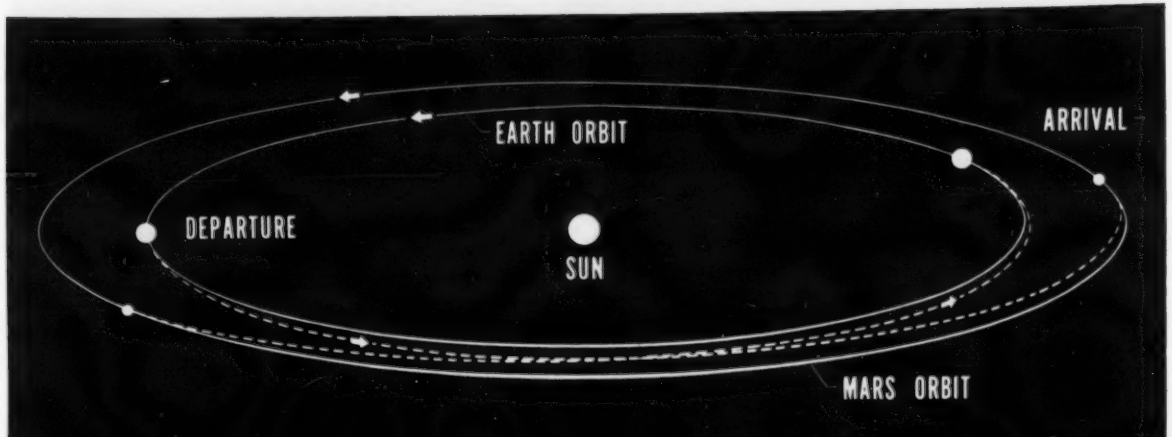


FIGURE 130

MINIMUM-ENERGY FLIGHT PATH FOR MARS ROUND TRIP



TIME IN DAYS FOR MARS JOURNEY

SYSTEM	ESCAPE FROM EARTH	COAST	DESCENT TO MARS ORBIT	WAIT	TOTAL
WEIGHT / THRUST = 5,000	59	259	31	403	1062
HIGH THRUST ROCKET	—	259	—	455	973

FIGURE 131

MARS VEHICLE

Figure 132 shows an electric space vehicle for accomplishing this eight-man Mars expedition. This is the vehicle which would be launched into orbit to start the men on their way to Mars. The overall length is around 600 feet for this configuration. Electric power required is about 12,000 kilowatts. Thrust is only 58 pounds. We have the nuclear reactor system with its shielding and propellant tank. The propellant goes through a pipe and is ejected by the electric accelerating apparatus at the back end. The turbogenerator generates the electric power, which is supplied to the accelerator to accelerate the propellant out at large speeds. There is the crew cabin, and the landing craft on which part of the crew will settle onto Mars for exploration purposes. A weight breakdown of this system is something as follows: For the cabin, which includes all the communication and navigation equipment and the environment controls, as well as the crew, about 50,000 pounds. A subsistence allowance, including food, water, and oxygen of the crew, about 85,000 pounds. Landing craft with exploration equipment, 40,000. A powerplant weighs about 76,000 pounds, and the propellant about 70,000 pounds. And we have allowed 29,000 pounds of reserves.

The gross weight of the entire system is about 350,000 pounds, for the most economical path which gives us the least weight. If we increase this to something like 450,000 pounds, we think that with the ultimate development of the nuclear electric propulsion system, we may be able to reduce the Mars round-trip time to about a year and a half with fairly reasonable total launching weights. It takes more weight to supply the crew than it does to supply the powerplant in this case. So anything we can do to reduce this would be very advantageous from a weight standpoint.

CURRENT STATUS

In the past year considerable progress has been made in the research and development of electric propulsion systems. At that time, only a few laboratory-sized electric rockets had been operated, and these only in very inadequate facilities. Furthermore, no electric powerplants suitable for electric space propulsion systems were under development.

Since that time, facilities have been completed at the NASA Lewis Research Center for continuous testing of larger electric rockets. These facilities consist of four vacuum tanks, three of which are 5 feet in diameter and 16 feet long. Two types of ion rocket have been tested in these facilities, and several more are being designed and built. The results indicate that, although much improvement is still needed, the performance required for space propulsion should be attainable.

The facilities now available, however, are still too small to test ion or plasma rockets of the size needed for space missions. In the NASA appropriations for fiscal year 1960, a sum was included for a facility to test electric rockets in the range of power and thrust needed for the propulsion of interplanetary probe vehicles. Design of this facility is proceeding, and construction contracts for parts of the facility

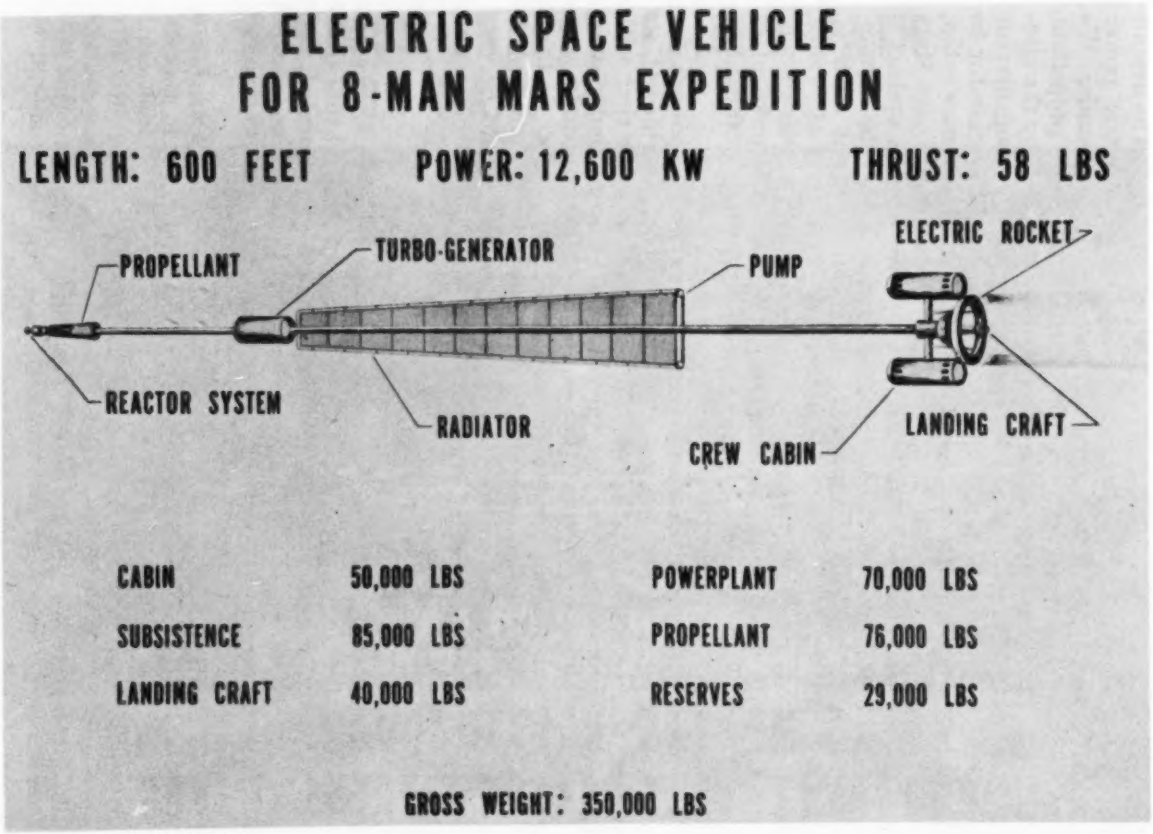

ELECTRIC SPACE VEHICLE
FOR 8-MAN MARS EXPEDITION
LENGTH: 600 FEET
POWER: 12,600 KW
THRUST: 58 LBS
PROPELLANT
TURBO-GENERATOR
PUMP
ELECTRIC ROCKET
REACTOR SYSTEM
RADIATOR
CREW CABIN
LANDING CRAFT
CABIN 50,000 LBS
SUBSISTENCE 85,000 LBS
LANDING CRAFT 40,000 LBS
POWERPLANT 70,000 LBS
PROPELLANT 76,000 LBS
RESERVES 29,000 LBS
GROSS WEIGHT: 350,000 LBS

FIGURE 132

are expected to be let within the next few months. It is expected that the complete facility will be ready for operation in about 2 years.

In the realm of electric power supplies, a contract will soon be let to develop a system (Snap 8) which is capable of generating enough power (30–60 kilowatts) to operate the electric rockets which will be needed for interplanetary probe missions.

Further study of missions for electric propulsion systems has confirmed our expectation mentioned in last year's testimony that the round-trip time for an Earth-Mars mission can be reduced from about 1,000 days to about 600 days without excessive increase in the initial weight needed. These trip times, of course, depend on practical attainment of the low powerplant weights which theoretical studies have indicated to be feasible.

In summary, although electric propulsion is still in the research stage, the experimental and theoretical studies completed during the last year have increased our confidence that this method of space propulsion will be tremendously useful for both manned and unmanned space missions of the future.

ELECTRIC ROCKETS

By J. Howard Childs, Chief, Electric Propulsion Branch, NASA Lewis Research Center, Cleveland, Ohio

ION ELECTRIC ENGINE

Figure 133 shows a simplified diagram of a typical ion rocket engine. The propellant is pumped from tanks which store the liquid and enters the engine. It flows first into the vaporizer. The vaporizer is heated electrically by heating coils, and becomes filled with propellant vapor. This vapor then flows through many orifices in a distributor plate, so-called because it is designed to evenly distribute the vapor onto the ionization grids. These ionization grids must operate at a high temperature, so they, too, are heated electrically; and furthermore, they must be made of some material which has a higher affinity for electrons than does the propellant itself. One combination which shows a lot of promise is metallic cesium as the propellant, because it has a low affinity for electrons, and tungsten as the metal from which the ionization grids are fabricated because it has a high affinity for electrons. Using this combination, each time an atom of cesium comes in contact with the heated tungsten grids, one electron leaves the cesium atom and falls into the tungsten metal. When the cesium atom loses one of its electrons, it has a positive charge and is, by definition, then an ion. Thus flowing away from these ionization grids is a stream of positively-charged cesium ions.

Now, we connect the ionization grids and the engine housing around them to the positive terminal of the electric generator. It produces a voltage and causes an electric current to flow. In the particular example we are showing here, this generator is capable of producing 40,000 volts, the ionization grids and the engine housing around them, are operating at 40,000 volts.

53795 O—60—pt. 2——16

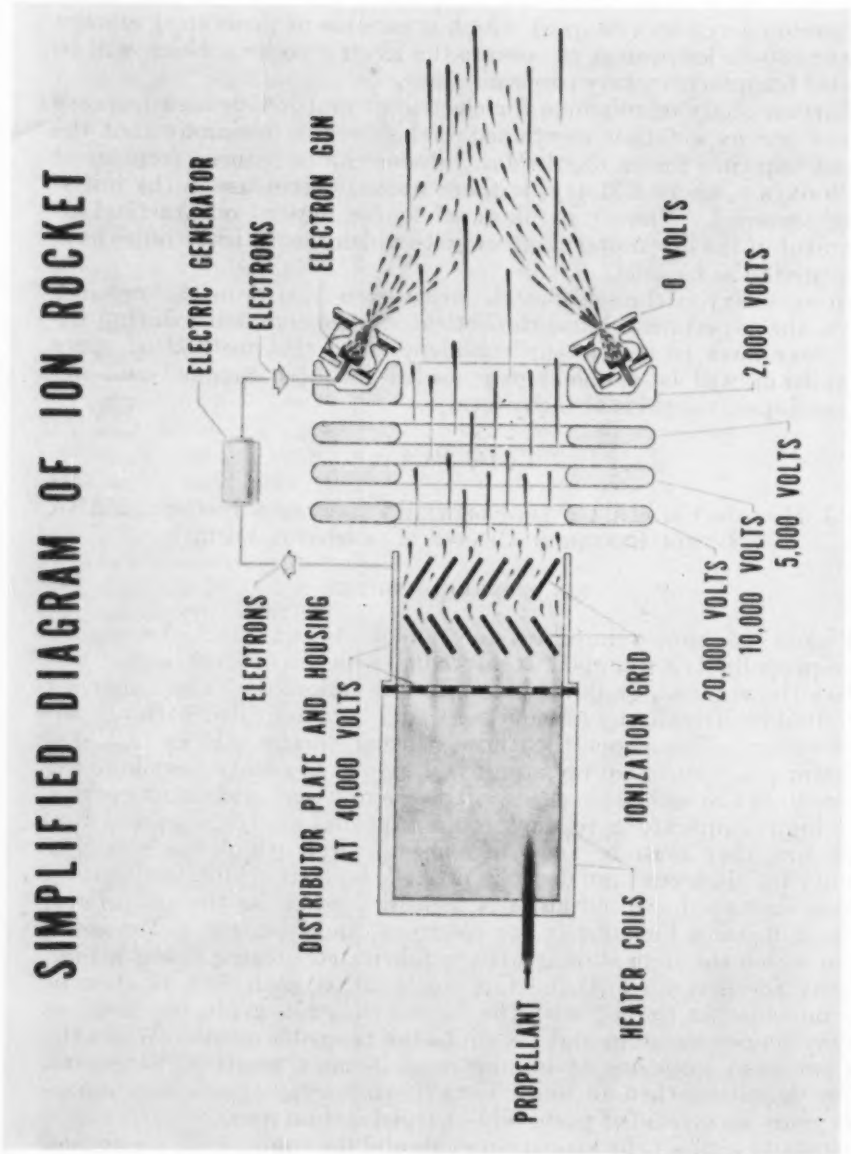

SIMPLIFIED DIAGRAM OF ION ROCKET
ELECTRIC GENERATOR
ELECTRONS
ELECTRON GUN
0 VOLTS
2,000 VOLTS
ELECTRONS
DISTRIBUTOR PLATE AND HOUSING
AT 40,000 VOLTS
20,000 VOLTS
10,000 VOLTS
5,000 VOLTS
IONIZATION GRID
PROPELLANT
HEATER COILS

FIGURE 133

Since these metal parts are at such a high voltage, and since the cesium ions are also postively charged, it means that the ions are repelled away from these metal parts by an electrostatic force. As the ions move downstream through the engine, they enter regions in the engine where the voltage is progressively lower. As these positive ions move into the regions of lower voltage, they are acted on all the while by these electrostatic forces, and they accelerate as they travel along. This acceleration of the ions under the action of these electrostatic forces is exactly the same as the acceleration an object experiences when it falls under the action of gravity. So, by the time our ions have fallen to the back of the engine, they have attained a very high velocity, and it is this high velocity jet of ions which produces the thrust necessary to propel a spacecraft.

Negatively charged electrons that were given off back at the ionization grids, where the positively charged ions were created, flow away through the external wiring. The electric generator is necessary to force the electrons to flow from the region where the voltage is high to the region at the back of the engine where the voltage is low. The generator acts like an electron pump. It does the work of pumping these electrons through the wires in the same way a conventional pump does the work of forcing liquids uphill through pipes.

The electron gun is a device for accelerating these electrons outward in a jet or beam, using electrostatic forces in exactly the same way that the ions were accelerated. So we have a beam of ions and a beam of electrons that is directed into the ion beam in such a way that the electrons will mix with the ions and eventually neutralize their charge. The ions are charged positively and the electrons negatively, so when they get together the overall charge will be neutral, or zero.

The electrons are such lightweight particles that they do not contribute any appreciable amount to the thrust, but it is nevertheless important that we eject them in this manner. If we simply ejected the positively charged ions and retained the negative electrons on board the space vehicle, then quite obviously it would build up a tremendous negative electrical charge. We would then have a negatively charged spacecraft and a cloud of positive ions in space behind the vehicle, and there would then be an electrostatic force of attraction between these positively charged ions and the negatively charged space vehicle which would slow down the space vehicle. So by ejecting the electrons in this way, we can prevent this from happening.

NASA ION PROPULSION RESEARCH

The NASA is conducting research on each of the components of this type engine. In one of our laboratories we are investigating the vaporization of various propellent materials, and we are studying the flow rates of these propellants through orifices of the type used in our engines. In other apparatus we are studying the effectiveness of heated tungsten and other materials in converting propellants into ions. In addition to the work with cesium as propellant, we are also trying to find other materials which would make suitable propellants for an ion rocket. We are also examining other types of ion sources which differ rather markedly from the one illustrated. These include electric arcs and certain types of high-frequency electrical discharges

in gases that are known to produce some ionization. We are also conducting research on various ion accelerator configurations to determine which configurations will most efficiently accelerate these ions to the necessary high velocity with a minimum of ion impingement on the metal parts. This is quite important, because any impact of the high-velocity ions on the metal will cause severe erosion of the metal and will greatly reduce the operating life of the engine. Finally, we are doing research with electron emitters to determine the best method for neutralizing the ion beam.

As we determine the necessary design principles from this research with the various engine components, we make use of these data to design and build small-scale ion rocket engines which can then be tested in rather elaborate large vacuum tank facilities.

The Lewis Research Center now has four large vacuum tanks in operation. In these tanks we can test the ion and plasma rockets at pressures below one-billionth of sea level atmospheric pressure. Many of the facts which follow were obtained from these vacuum tank tests (figs. 134 and 135).

We have operated two experimental ion rocket engines for a total of over 50 hours on each engine. Power efficiencies as high as 58 percent have been measured at very high values of specific impulse (20,000 seconds). Propellant utilization efficiencies as high as 85 percent have been measured. The ion rockets showed reasonable durability, considering the preliminary status of the design art for this type engine. Additional research is underway to further improve the efficiency and durability of these engines. Also, one major question remains to be answered: "Can we neutralize the positive ion beam by addition of negative electrons at the back of the engine?" At least partial beam neutralization is occurring inside our vacuum tanks, but electrons emitted from the tank walls may be contributing to this neutralization. Present research is directed toward determining the magnitude of the effect of the tank walls.

One of the engines we are building to test in the tank is shown in figure 136. This engine has in it all the operating principles and components that were in the simplified diagram just described. Here, where we deal with a practical engine, it becomes necessary to locate many of these parts very close together so the whole thing becomes very compact.

We are not alone in this field of research. Several companies are also conducting research on the ion rocket. At the present time no one has yet demonstrated an ion rocket engine which has all the performance features necessary to make it a practical device for space propulsion. The requirements are varied and very stringent, and include such things as the ability to produce a high-velocity jet of ions and to do it with substantially 100 percent efficiency in converting the electric input energy into kinetic energy of the exhaust beam of ions. An engine to be practical must ionize essentially all of the propellant that you feed into the engine, and in addition it must produce a reasonable amount of thrust for a given engine size. With the type of research program which is underway in the NASA and in industry, it appears quite probable that we will have small-scale ion rocket engines in operation which have these performance characteristics by the time the electric power generating equipment has been developed to the point where test of an overall propulsion system might begin.

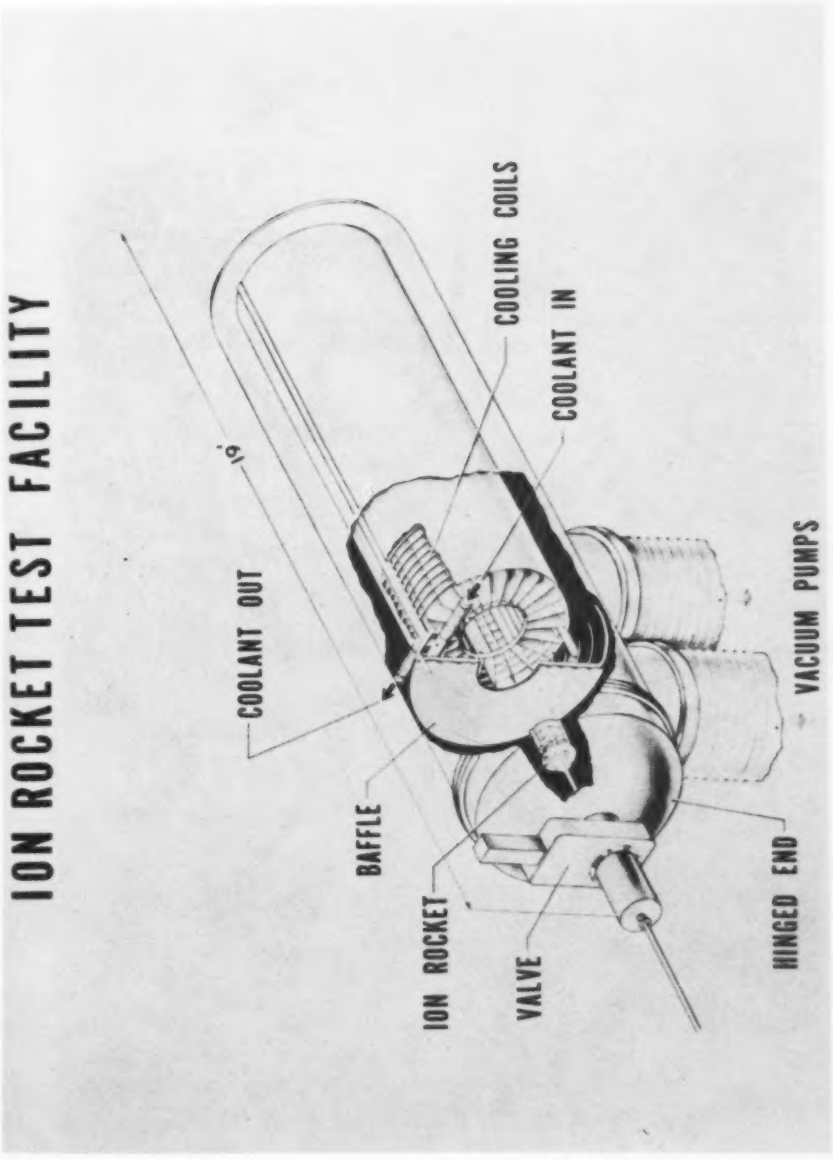

ION ROCKET TEST FACILITY
COOLANT OUT
COOLING COILS
COOLANT IN
BAFFLE
ION ROCKET
VALVE
HINGED END
VACUUM PUMPS

FIGURE 134

ION ROCKET TEST FACILITY

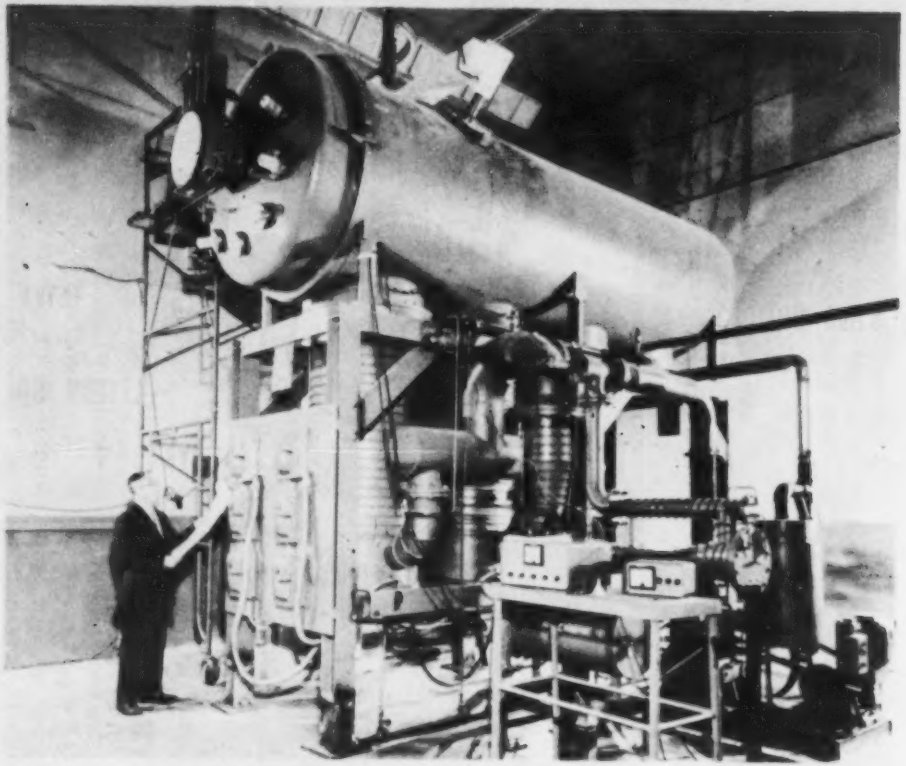


FIGURE 135

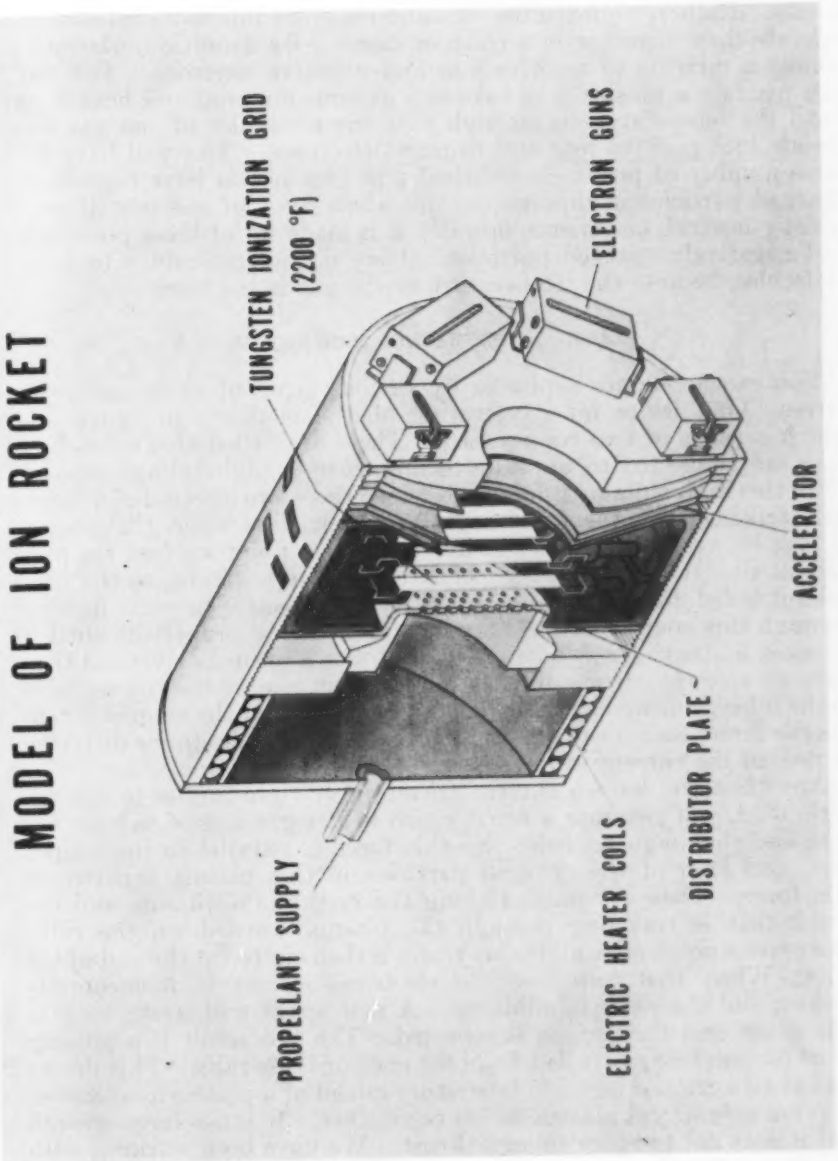

MODEL OF ION ROCKET
TUNGSTEN IONIZATION GRID
(2200 °F)
ELECTRON GUNS
ACCELERATOR
PROPELLANT SUPPLY
ELECTRIC HEATER COILS
DISTRIBUTOR PLATE

FIGURE 136

THE PLASMA ROCKET

The plasma rocket differs from the ion rocket in that we do not separate the ions and the electrons and eject them in two separate beams. Rather, we leave the ions and electrons intermingled and accelerate them together in a common beam. By definition, plasma is simply a mixture of positive ions and negative electrons. The way you produce a plasma is to take any gaseous material and heat it up until the temperature is so high that the molecules of the gas dissociate into positive ions and negative electrons. You will have the same number of positively charged particles as you have negatively charged particles in this gas, so the whole mass of gas is still electrically neutral, but microscopically it is made up of these positively and negatively charged particles. They do not recombine to form molecules, because the temperature of the gas is too high.

PLASMA ACCELERATION TECHNIQUES

You can accelerate a plasma by various types of electromagnetic forces. One device for accelerating plasma is shown in figure 137, which consists of two copper bars. These are called electrodes, and they are connected to opposite terminals of a high-voltage supply. With this high voltage difference between these two electrodes, a spark will strike between them. The spark will form first where the spacing is least between the two electrodes, and at this point we feed the propellant in. It is fed in as a gas through a hollow tube, so the propellant is fed directly into the spark and the electric currents flowing through this spark serve to heat up the incoming propellant until it becomes ionized. That is, it converts it into a plasma. We will then have an electric current flowing across from one of the copper bars to the other, and we have a magnet arranged so that the magnetic field has the direction indicated by the arrow at right angles to the direction of flow of the current in the spark.

Any time you have a current traveling at right angles to a magnetic field, you generate a force which is at right angles to both the core and the magnetic field. So this force is parallel to the copper bars, and each of the charged particles in this plasma experiences this force. They are pushed along the rails so the plasma and the spark that is traveling through the plasma move down the rails. The plasma accelerates all the way, and is then ejected at the end of the rails. When that happens, the electrical circuit is momentarily broken, and the voltage builds up. A new spark will strike back at this point, and the process is repeated. The end result is a pulsing jet of plasma being expelled from the ends of these rails. This device we have diagramed here is a laboratory model of a plasma accelerator. It is not a practical plasma rocket engine yet. It is not large enough and it does not produce enough thrust. We have been working with this device for some time. We know we do get high-velocity plasma being ejected from it. We get some thrust from it, but we do not yet have the types of instrumentation necessary to determine its exact performance and its efficiency. The instrumentation is now being developed, and we will continue work with this device.

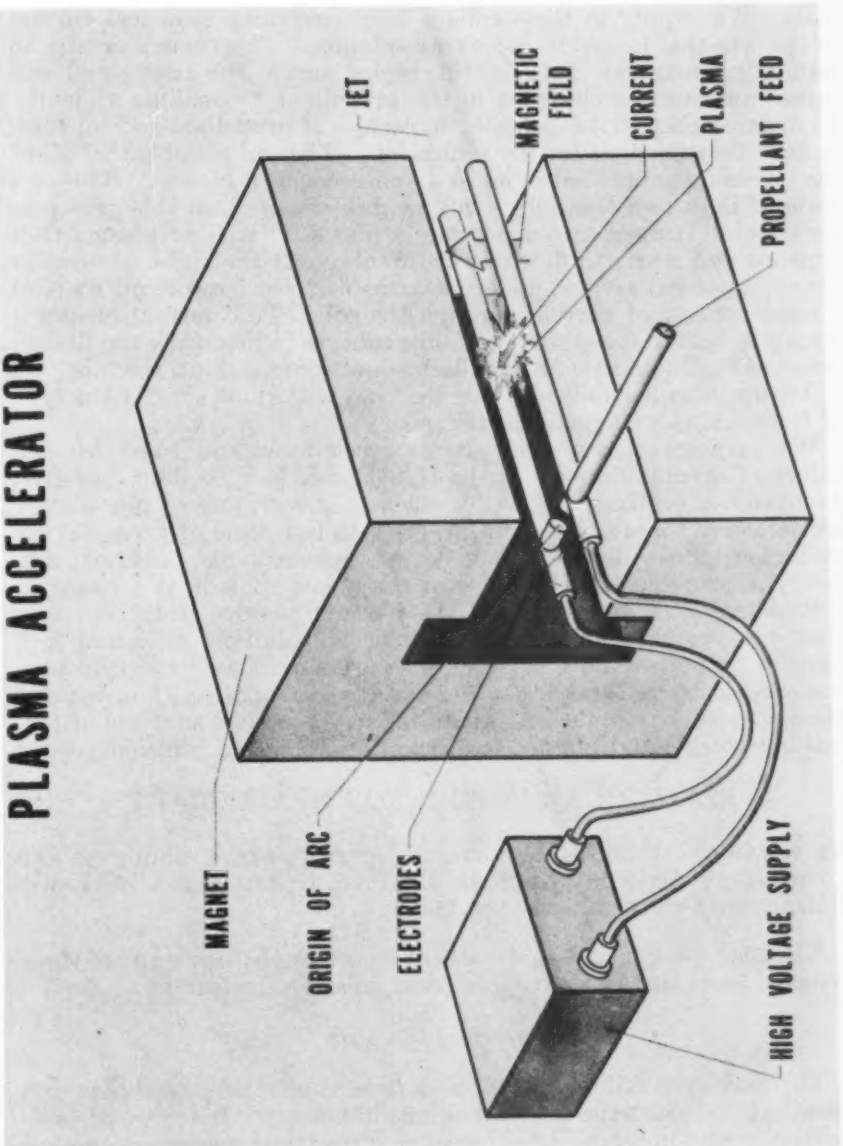

PLASMA ACCELERATOR
JET
MAGNETIC FIELD
CURRENT
PLASMA
PROPELLANT FEED
MAGNET
ORIGIN OF ARC
ELECTRODES
HIGH VOLTAGE SUPPLY

FIGURE 137

Another type of plasma accelerator is shown on figure 138. It is entirely different from the one just described. Again it is a laboratory model. It consists of a long glass tube. The propellant is fed in as a gas and around the outside of our glass tube we have several copper coils. We supply to these coils a high-frequency electrical current of the type that is used in radio transmission. This current creates an oscillating magnetic field in the region inside the tubes, and this causes any ions or electrons in the propellant to oscillate violently. In so doing they strike incoming molecules of propellant and hit them so hard they produce further ionization. The end result is that all of the incoming propellant is ionized and becomes a plasma. This is a form of induction heating. Only in this case we heat this gas up to such a high temperature it becomes a plasma. The hot plasma then expands and starts to flow down the tube. At the right moment in time when it has arrived underneath the first accelerator coil we send a sudden burst of current through the coil. This current creates a magnetic field in the region inside the tube, as indicated by the dashed lines, and this will squeeze the plasma and shove it down the tube.

Anyone who has milked a cow by hand will know exactly the type of force that this magnetic field exerts.

We have operated several plasma accelerators and have obtained values of specific impulse up to 11,000 seconds. To date, however, we have not obtained reasonable efficiencies with any of our plasma accelerators. Work is now in progress to test some of these devices at higher power levels in our large vacuum tank facilities; efficiency measurements will be one of the prime goals in this research.

Basic research in support of the ion and plasma rocket development has provided valuable data on propellant flow rates and flow control, propellant flow patterns inside the engines, ionization phenomena, electrical breakdown, and materials compatibility in ion and plasma rocket environment. In addition, theoretical analyses of several ion rockets and plasma accelerators have been completed.

ELECTRICAL POWER FOR SPACECRAFT

By Robert E. English, Associate Chief, Power Production and Shielding Branch, Nuclear Reactor Division, NASA Lewis Research Center, Cleveland, Ohio

Electric power for use in space can be obtained by using any of three types of basic energy source: chemical, solar, or nuclear.

CHEMICAL SYSTEMS

The flashlight cell is a familiar source of electric power that uses chemical energy as the primary source of energy. Batteries of lead-acid cells used in automobiles for storing electrical energy are another example of chemical-electrical systems. Performance superior to that provided by either of these familiar types is provided by silver-zinc cells that have recently been developed for use in aircraft, missiles, and space vehicles. For typical missions in space, the weight required for chemical systems is high and increases with the length of the intended period of use. For example, production of 1 kilowatt of electric

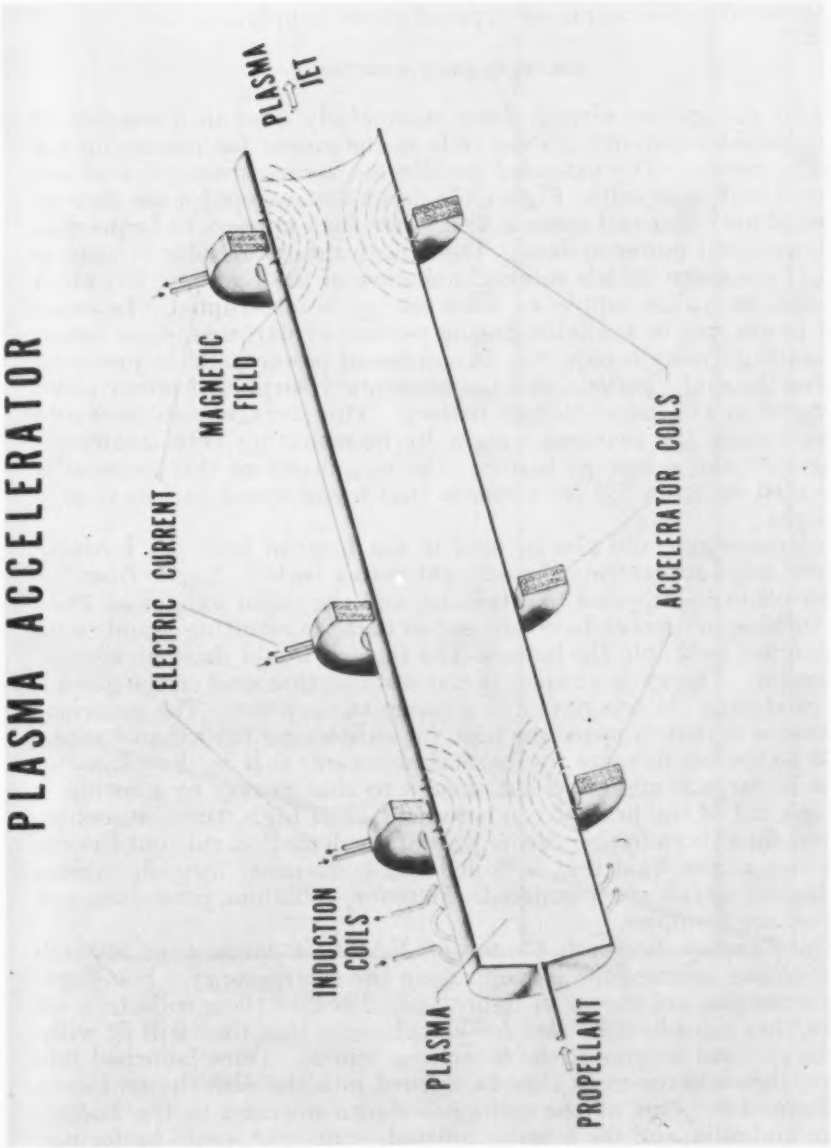

PLASMA ACCELERATOR
PLASMA JET
MAGNETIC FIELD
ELECTRIC CURRENT
ACCELERATOR COILS
INDUCTION COILS
PLASMA
PROPELLANT

FIGURE 138

power for 1 day would require 1,000 pounds of lead-acid cells; 1 kilowatt for 2 days would require 2,000 pounds of lead-acid cells. Although the weights of chemical power supplies can be potentially less than the figures cited here, such systems would still not successfully compete with other advanced types of power supply.

SOLAR ENERGY SYSTEMS

Solar energy has already been successfully used in a number of space vehicles employing solar cells as the means for producing the electric power. The extended paddles on recent space vehicles are covered with solar cells. Figure 139 shows that, except for the shortest times of use, solar-cell systems weigh less than appears to be possible with chemical power systems. One disadvantage of solar systems is that if the space vehicle enters the shadow of the Earth, or any other celestial body, the supply of solar energy is interrupted. In order that power can be available during periods of darkness, some means for storing energy is required. An excess of power could be produced during the sunlit periods, and the momentary surplus of power could be stored in a chemical storage battery. This storage problem would thus increase the required weight by necessitating both additional solar cells and a storage battery; the magnitude of this increase is indicated in figure 139 for a system that would spend half its time in sunlight.

Solar energy could also be used in the form of heat. A focusing mirror could concentrate the sunlight onto a boiler. Vapor from the boiler could be supplied to a turbine, and the vapor exhausted from the turbine could then be condensed so that the resulting liquid could be pumped back into the boiler. The turbine would drive an electric generator. This cycle of operation is just like that used on the ground for producing electric power in a steam powerplant. The principal difference is that in space the heat for condensing the exhaust vapor must be ejected to space by thermal radiation; that is, the condenser must be large enough and hot enough so that merely by glowing it can get rid of the heat of condensation. The high temperatures required for this radiation of the heat of condensation rule out the use of water as the fluid that is boiled and condensed; instead, various lowboiling metals are considered. Mercury, rubidium, potassium, and sodium are examples.

The Langley Research Center of NASA is conducting research on focusing mirrors for concentrating the solar energy. Some specific examples are shown in figure 140. Because these collectors are large, they must be collapsed for launching so that they will fit within the payload section of the launching vehicle. Once launched into space, the collector must then be opened into the dish-shapes shown in figure 140. One of the collectors shown operates in the fashion of an umbrella, and the other is inflated. Sunlight would be focused onto the ball in the center of each mirror, and this ball is the boiler for the powerplant.

NUCLEAR ENERGY

Three types of nuclear energy source are considered: radioisotope, fission, and fusion. We presently have no program on the application of fusion to propulsion. Instead, we will wait until the AEC

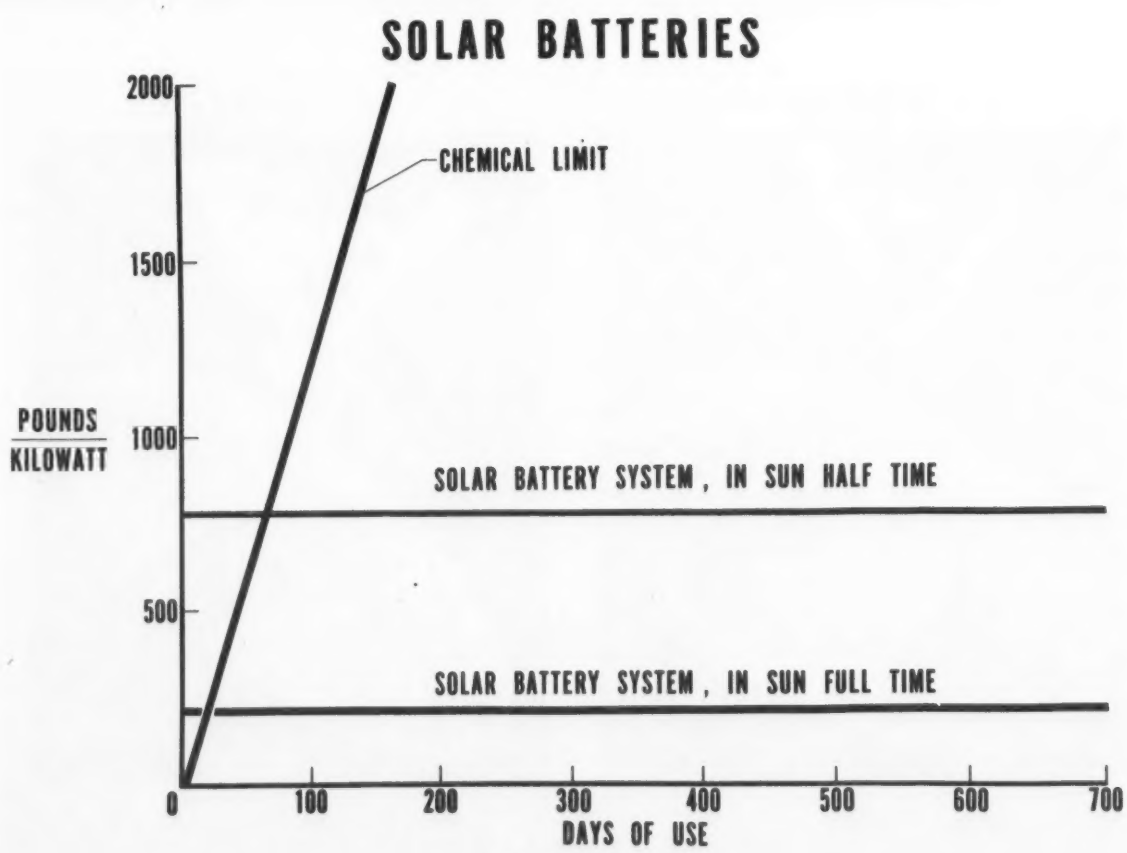

SOLAR BATTERIES
2000
1500
1000
500
0
POUNDS
KILOWATT
CHEMICAL LIMIT
SOLAR BATTERY SYSTEM, IN SUN HALF TIME
SOLAR BATTERY SYSTEM, IN SUN FULL TIME
100
200
300
400
500
600
700
DAYS OF USE

FIGURE 139

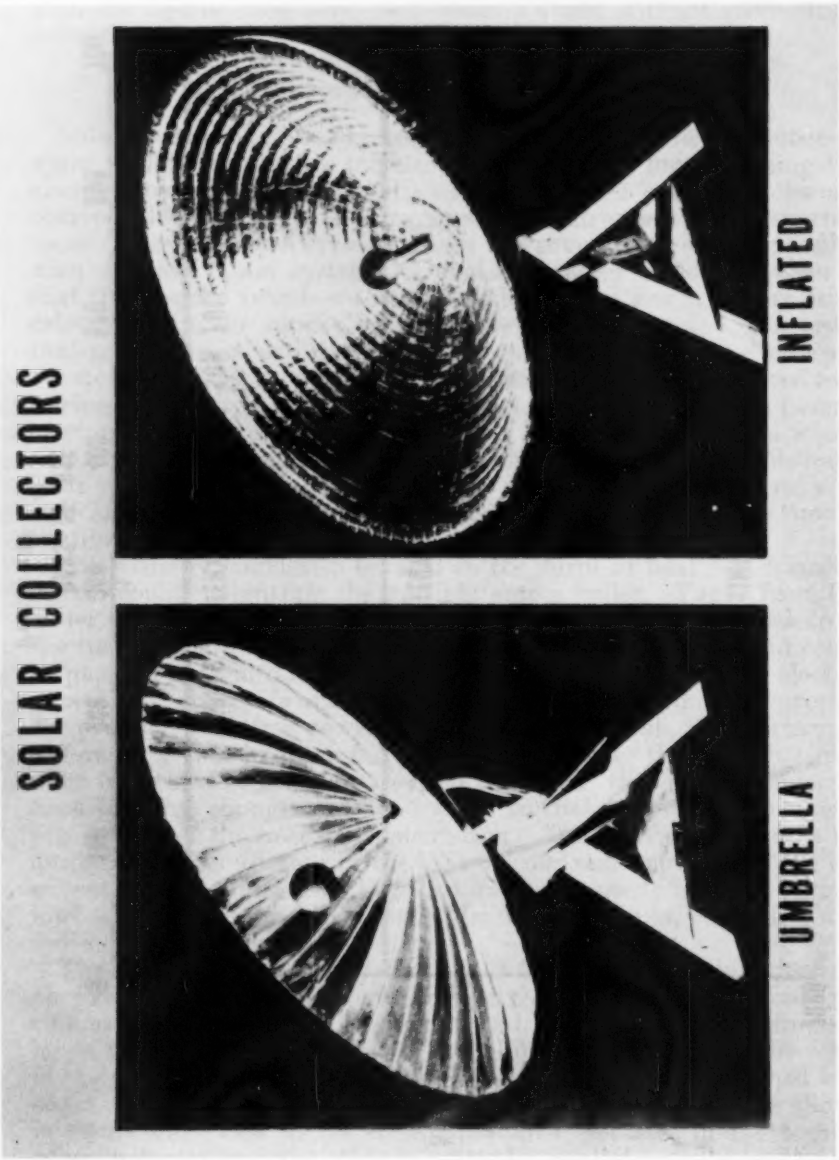


FIGURE 140

has further advanced its research on fusion before we do anything on its application to space propulsion. Radioisotopes and nuclear fission reactors are thus the types of nuclear energy we are considering for application in space.

Radioisotopes are familiar to everyone as the radium in a luminous dial of a watch, cobalt 60 used in medical treatment, and strontium 90. A characteristic of radioisotopes is that they decay. By decay I mean the power output of a radioisotope falls with time. This means that a device that uses a radioisotope would also have a decreasing power output. The rate of decline of the electric power output can be affected by the design of the power supply and by selection of the radioisotope. The decaying of any given isotope cannot be controlled; we can neither hasten it nor stop it. This continuous emission of energy by a radioisotope increases the hazard of such devices during preparation for launching and even during the launching itself. This hazard does not rule out the use of radioisotopes, but it does require additional precautions during the launching.

SNAP 3

The AEC is developing several types of electric power supply that will use radioisotopes. An example is Snap 3. This device converts heat from a radioisotope into electric power by employing the thermoelectric principle. This familiar principle has in the past been principally used for measurement of temperature by means of thermocouples and thermopiles. Recent technical advances have permitted useful application of this technique in generation of small amounts of electric power.

SNAP 2

Among the systems that the AEC is developing for production of electric power, Snap 2 is an example of one that uses a nuclear reactor. This system uses heat from the reactor to boil mercury, and the mercury vapor drives a turbine and generator. The electric power of 3 kilowatts from Snap 2 is about 10 times that employed on any space vehicle to date. We thing that this program is a very good one, and that this particular kind of device, a reactor in combination with a turboelectric system, is the most promising type for producing large amounts of electric power, especially for electric propulsion.

One requirement of such systems is high temperature. The largest component of such a system is the radiator for disposing of the heat of condensation of the vapor. This radiator, because of its large size and the light construction required of space vehicles, is especially vulnerable to damage by meteoroids. Figure 141 shows how the weight of this radiator is affected by its operating temperature. If the radiator is at 700° F., its weight will be over half the total weight of the powerplant. If the radiator temperature can be increased, then the size and weight of the radiator can be so reduced that its weight is comparable with the weight of the other components of the powerplant. We thus seek to operate such systems at high temperature.

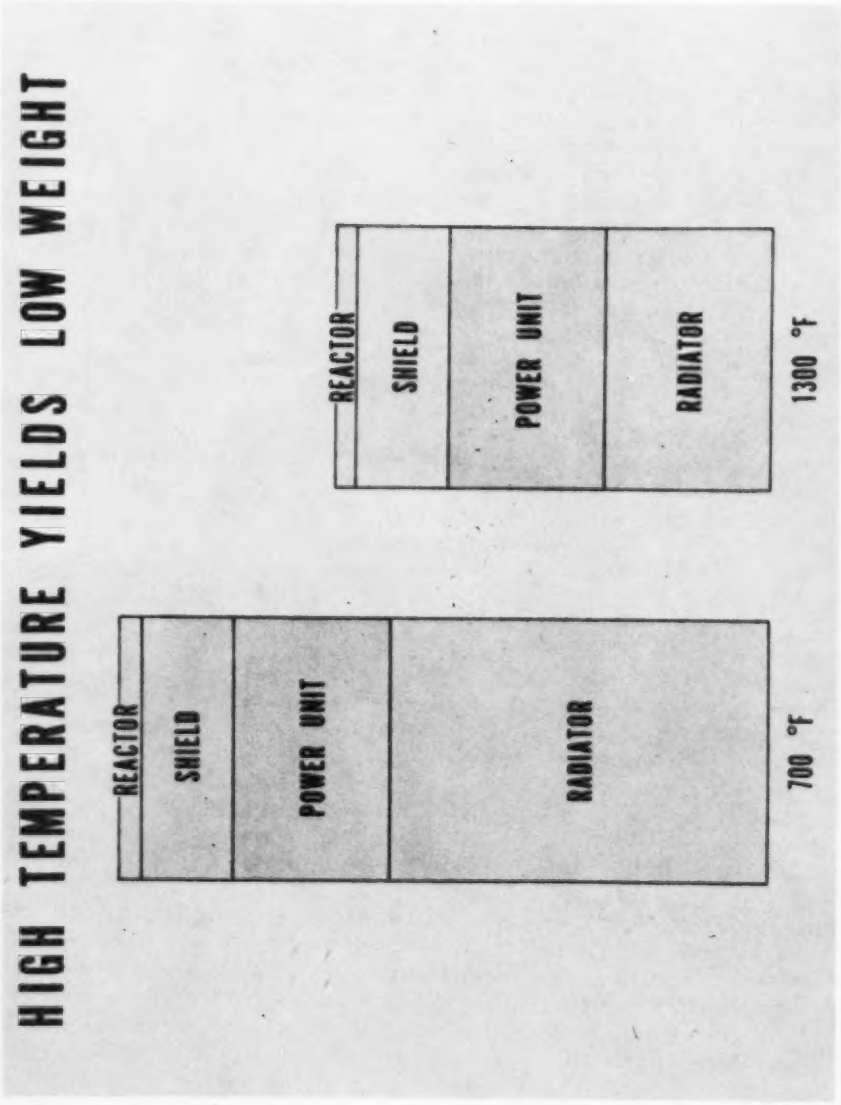

HIGH TEMPERATURE YIELDS LOW WEIGHT
REACTOR
SHIELD
POWER UNIT
RADIATOR
700 °F
REACTOR
SHIELD
POWER UNIT
RADIATOR
1300 °F

FIGURE 141

SNAP 8

The NASA and the AEC have begun a joint effort to develop a 30- to 60-kilowatt power supply that has been given the name Snap 8. The AEC will provide the reactor for this system, and the NASA the machinery for converting the reactor's heat into electric power.

In many respects, the 30-kilowatt system will be much like the 3-kilowatt Snap 2 system. Snap 8 is intended to have two power ratings, 30 and 60 kilowatts. A 30-kilowatt system will be developed, and two such conversion systems will be combined in order to obtain 60 kilowatts. Because the reactor will have adequate capacity to support one or two conversion systems, a given reactor will be used for production of either 30 or 60 kilowatts of electric power.

The Snap 8 system will be useful for providing the auxiliary power that will be required for long range, long life, detailed communications from lunar and interplanetary missions. In addition, it will provide sufficient power for application to early electrical propulsion devices. Two such useful missions are (1) sending an instrumented probe to Mars and (2) raising a communication satellite to a 24-hour orbit.

Anticipated performances of space vehicles that use Snap 8 for electric propulsion are shown in figures 142 and 143. In each case, the 60-kilowatt version of Snap 8 was assumed to be launched into an orbit that is 300 miles above the Earth. The satellite in this orbit was taken to weigh 9,000 pounds, about the capacity of the Centaur launching vehicle. After a stable orbit about the Earth has been attained, the reactor and the conversion machinery would be started. This procedure was selected as being a safe way to use nuclear power for this application. The electric power would be supplied to an electric rocket for propulsion of the space vehicle to higher and higher orbits about the Earth.

Figure 142 shows the weights that could be boosted by this process into a 24-hour orbit. The 24-hour orbit is about 22,000 miles above the Earth's surface, and a satellite in this orbit would take just 24 hours in circumnavigating the Earth. A combination of three such satellites would be useful in a worldwide communication system in which signals from the ground would be received by one satellite, would be broadcast from that satellite to another, and would then be rebroadcast to the ground.

Three efficiencies for the electric rocket are given in figure 142 because the actual efficiency for the required operating conditions cannot yet be very well estimated in this case. The weight that Snap 8 could raise to this orbit varies considerably with the time permitted for the raising. By propelling for about 40 days, the electric propulsion system could raise a payload of 3,000 pounds to the 24-hour orbit.

A high-performance chemical rocket can place about 1,000 pounds of payload into a 24-hour orbit in the plane of the equator. For a communication satellite, part of this 1,000 pounds would be assigned to a communications equipment and part to the required electric power supply. The satellite raised by Snap 8 would, on the other hand, have the Snap 8 power supply in addition to its other payload. For this reason, a second scale of weights is shown at the right side of figure 142. This scale shows the combined weight of payload plus Snap 8 that would be raised into a 24-hour orbit. If the entire output of Snap 8

53795 O—60—pt. 2——17

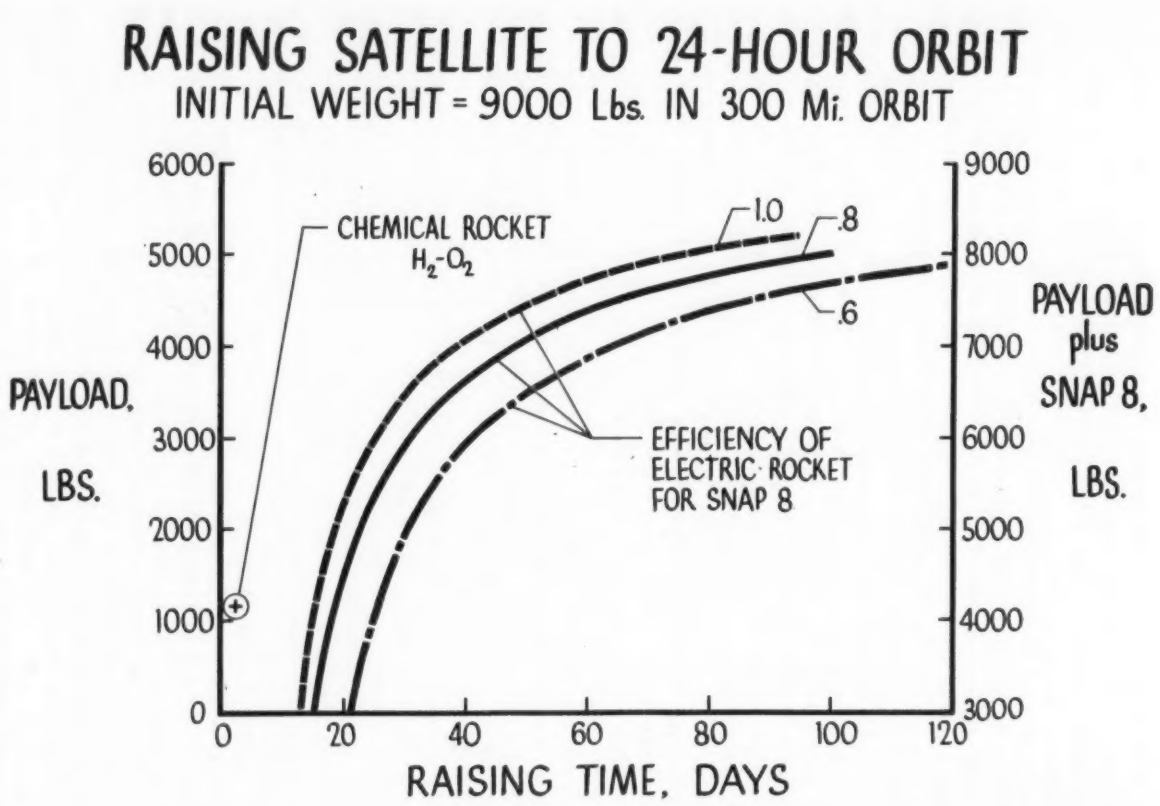

RAISING SATELLITE TO 24-HOUR ORBIT
INITIAL WEIGHT = 9000 Lbs. IN 300 Mi. ORBIT
PAYLOAD, LBS.
PAYLOAD plus SNAP 8, LBS.
CHEMICAL ROCKET
H_2-O_2
1.0
.8
.6
EFFICIENCY OF ELECTRIC ROCKET FOR SNAP 8
6000
5000
4000
3000
2000
1000
0
9000
8000
7000
6000
5000
4000
3000
0
20
40
60
80
100
120
RAISING TIME, DAYS

FIGURE 142

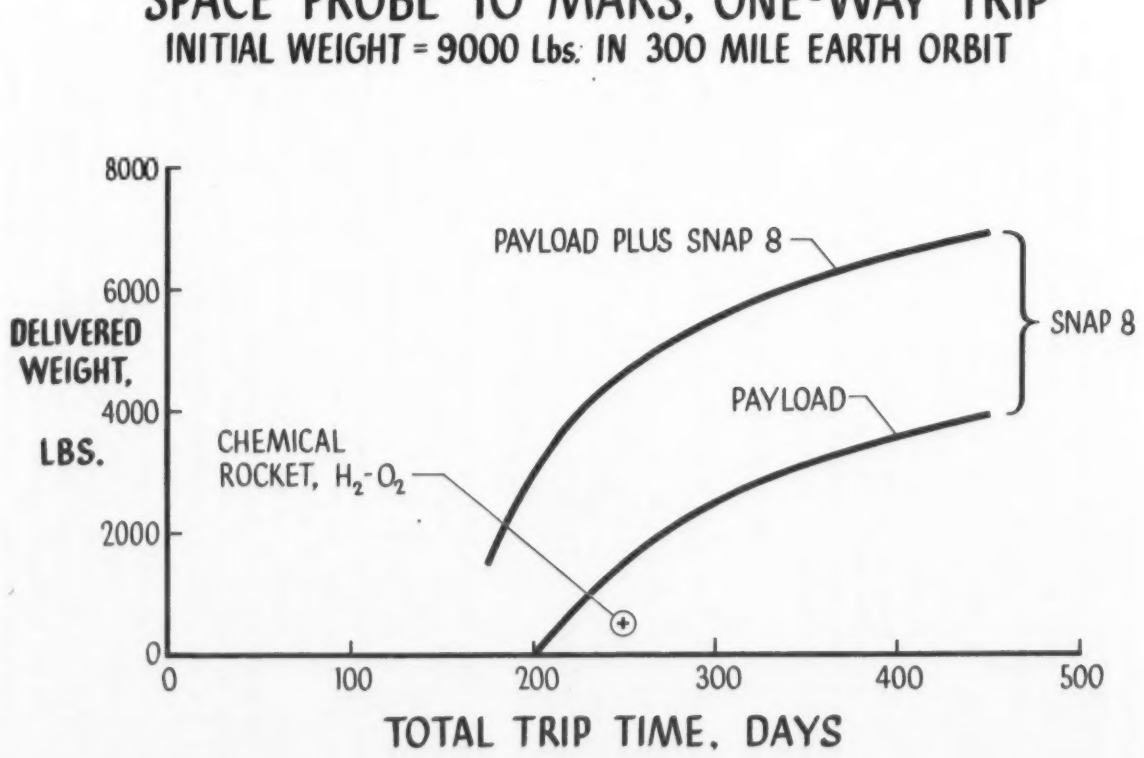

SPACE PROBE TO MARS, ONE-WAY TRIP
INITIAL WEIGHT = 9000 Lbs. IN 300 MILE EARTH ORBIT
8000
6000
4000
2000
0
DELIVERED WEIGHT, LBS.
PAYLOAD PLUS SNAP 8
SNAP 8
PAYLOAD
CHEMICAL ROCKET, H_2-O_2
0
100
200
300
400
500
TOTAL TRIP TIME, DAYS

FIGURE 143

is needed for the communications equipment, all of this weight can be classed as useful. If, say, only one-fourth of the 60 kilowatts is needed for communication, then only one-fourth of the weight of Snap 8 should be taken as a useful addition to payload. On either basis, Snap 8 is a very useful device for such a mission.

Another useful application is propelling an instrumented probe to Mars, for which estimated weights are given in figure 143. For both a chemical rocket and a Snap-8-propelled space vehicle, payload varies with the desired trip time. If the space vehicle is accelerated to a high speed in order to achieve a low transit time, the permissible payload is reduced. A high-performance chemical rocket could deliver about 500 pounds of payload to orbit about Mars in 250 days. Snap 8 could transport a comparable payload in the same period of time. But if the trip time were increased to 350 days, the payload could be 3,000 pounds. In addition to this payload, Snap 8's 3,000 pounds would also arrive at the destination, and 60 kilowatts of electric power would be available for use by the payload.

NUCLEAR ROCKETS

By Harold B. Finger, Chief, Nuclear Engines Program, NASA

The subject covered in this section is space performance capabilities of nuclear rockets, and will indicate why the NASA feels that the research and development effort on nuclear rockets must be very actively and diligently pursued.

NUCLEAR FISSION PROCESS

The nuclear fission process depicted in figure 144 shows a neutron colliding with a uranium nucleus, splitting it into two main fission fragments which go off in opposite directions and which carry the major part of the energy of the fission process. About 90 percent of the energy of the fission process is contained in these fragments. This fission process also gives off about two neutrons which then go on to collide with other uranium nuclei, producing a self-sustained fission process. Also we have radiation given off in the form of alpha particles, beta particles, and gamma rays. We must provide shielding to protect personnel and materials from these radiations. In the fuel element of a nuclear reactor, uranium 235 atoms are dispersed in a structural material. The colliding of the heavy fission fragments in the fuel element produces heat which is transferred to the coolant flowing around the fuel element.

Figure 145 is a sketch showing the nuclear rocket system including a liquid hydrogen propellant tank, a turbopump system, and the reactor. As the hydrogen passes through the reactor, past the fuel elements, it absorbs the heat that is generated in the fission process. This hot hydrogen is then expanded through the jet nozzle. The hydrogen is accelerated to velocities up to about 25,000 miles per hour and produces the rocket thrust. Also shown is the kind of a shield that might be used in a space system to protect against the nuclear harmful radiation.

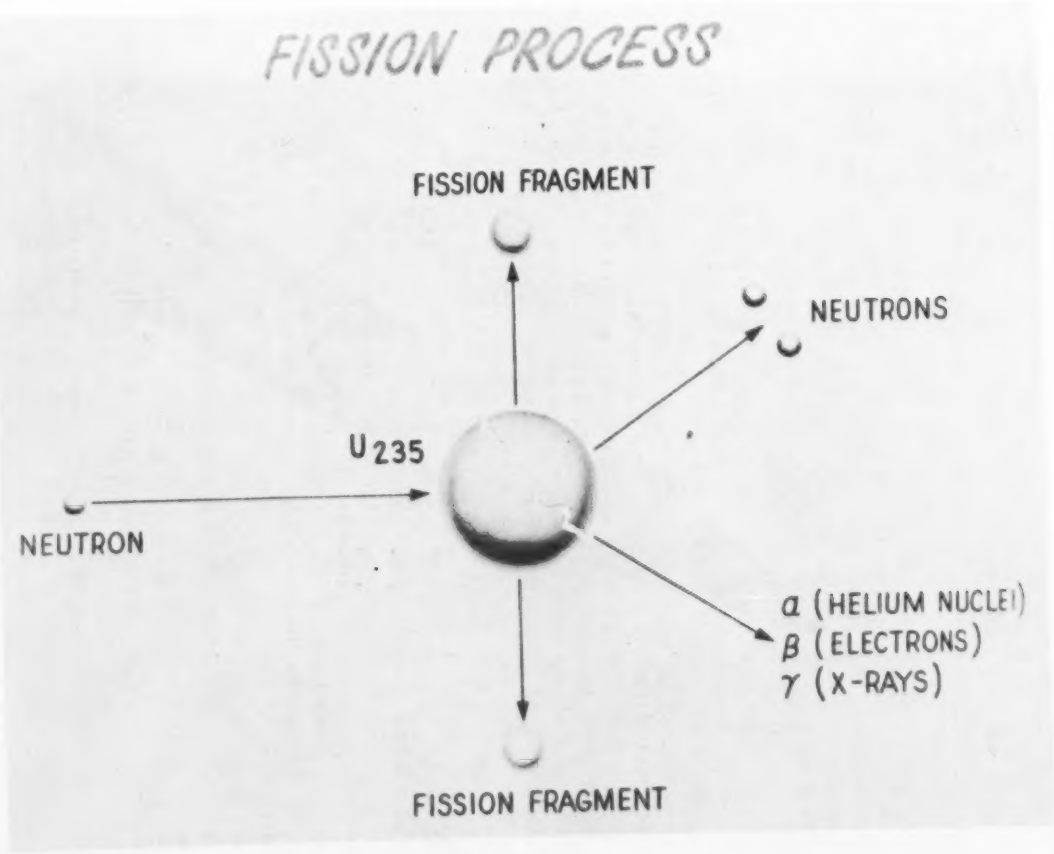

FISSION PROCESS
FISSION FRAGMENT
NEUTRONS
U 235
NEUTRON
α (HELIUM NUCLEI)
β (ELECTRONS)
γ (X-RAYS)
FISSION FRAGMENT

FIGURE 144

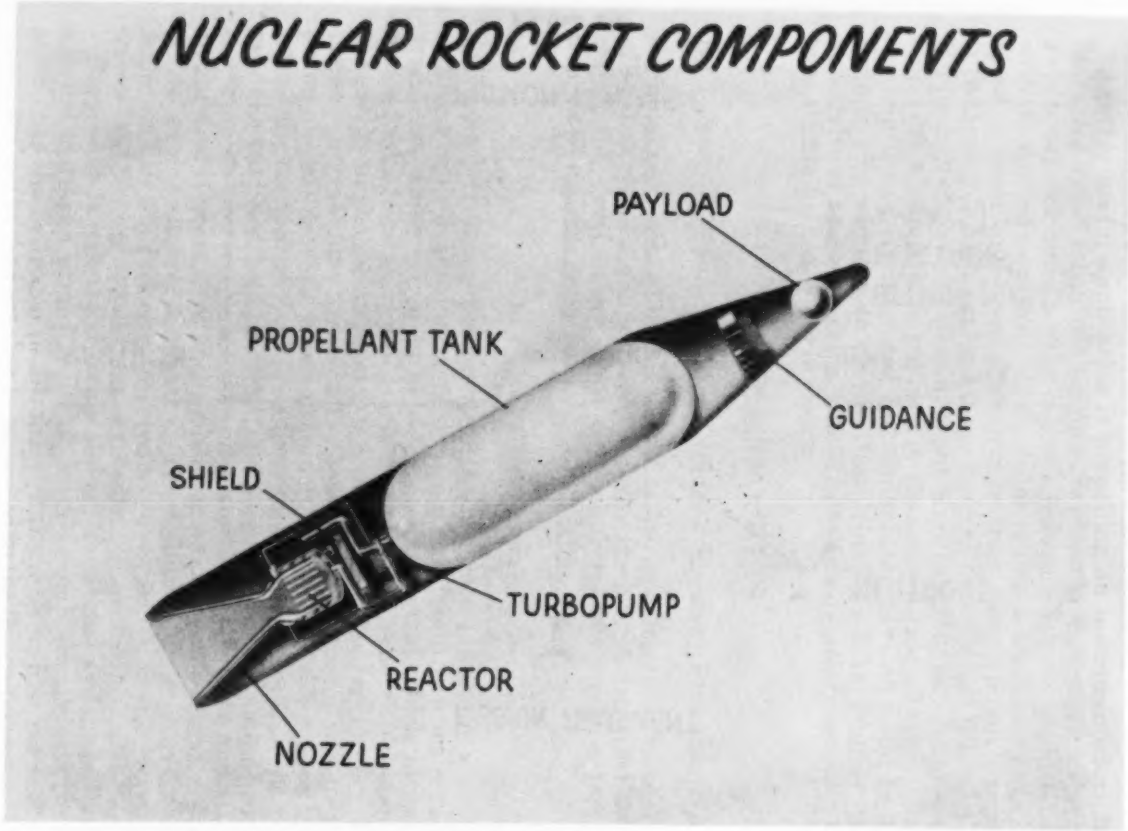

NUCLEAR ROCKET COMPONENTS
PAYLOAD
PROPELLANT TANK
GUIDANCE
SHIELD
TURBOPUMP
REACTOR
NOZZLE

FIGURE 145

IMPULSE

The important characteristic of the nuclear rocket is that it is potentially capable of giving much higher specific impulse than the chemical rocket systems. This high impulse or high thrust per pound of hydrogen flow per second reduces the total amount of propellant that is required to accomplish a given mission. This characteristic is illustrated in figure 146 which indicates the percentage of the gross weight of the vehicle that is required for propellant as a function of the specific impulse. Shown in figure 146 are the impulse ranges that can be achieved with chemical rockets, nuclear rockets, and electric rockets which will use nuclear electric power generating equipment. Figure 146 also presents the propellant requirements for all of these three propulsion systems for a Mars orbital round trip mission which departs from and then returns to the Earth orbit. It is apparent that the higher the specific impulse, the smaller is the portion of the vehicle gross weight that is required for propellant. The remainder of the gross weight is taken up by engine, structure, tankage, and payload. In addition, figure 146 indicates that a larger percentage of the vehicle gross weight may be made available for the dry weight of the rocket for the high impulse systems than for the low impulse systems.

When estimated weights for the nuclear rocket and electric rocket engine and structure are inserted, the payload capabilities shown in figure 147 indicate the marked potential advantages of using nuclear rockets over our chemical rocket systems for space propulsion. Also shown on the figure is the performance potential of nuclear-electric rockets. In this case, it is assumed that the gross weight of each of these rockets established in an Earth orbit is 150,000 pounds. This 150,000-pound rocket would be either a chemical, a nuclear, or an electric rocket. It leaves the Earth orbit and goes out to a Mars orbit round trip. The payload that returns to an Earth orbit is shown on the chart. The nuclear and electric rockets are comparable with each other and both are far above the value shown for the chemical rocket. In addition to the payload advantage, the nuclear and electric rockets may do this job with one stage while the chemical rocket will require at least three and probably four stages.

DEVELOPMENT OF BREADBOARD ENGINE

The NASA is working with the Atomic Energy Commission on a research and development program on nuclear rockets. The broad objectives of this program are shown in figure 148. The AEC, through its Los Alamos Scientific Laboratory, has prime responsibility for the evaluation of reactor feasibility which will be achieved with the demonstration of breadboard engine operation. The breadboard engine is a system which contains all of the principal components of the nuclear rocket, but is not packaged so as to resemble an operational engine system. In addition, the components are not necessarily flight-weight components. In support of the AEC program, the NASA is supplying certain nonnuclear components and the hydrogen propellant that is required for the program. With the completion of the breadboard engine demonstration, prime responsibility for the following steps of the program transfers to NASA with the

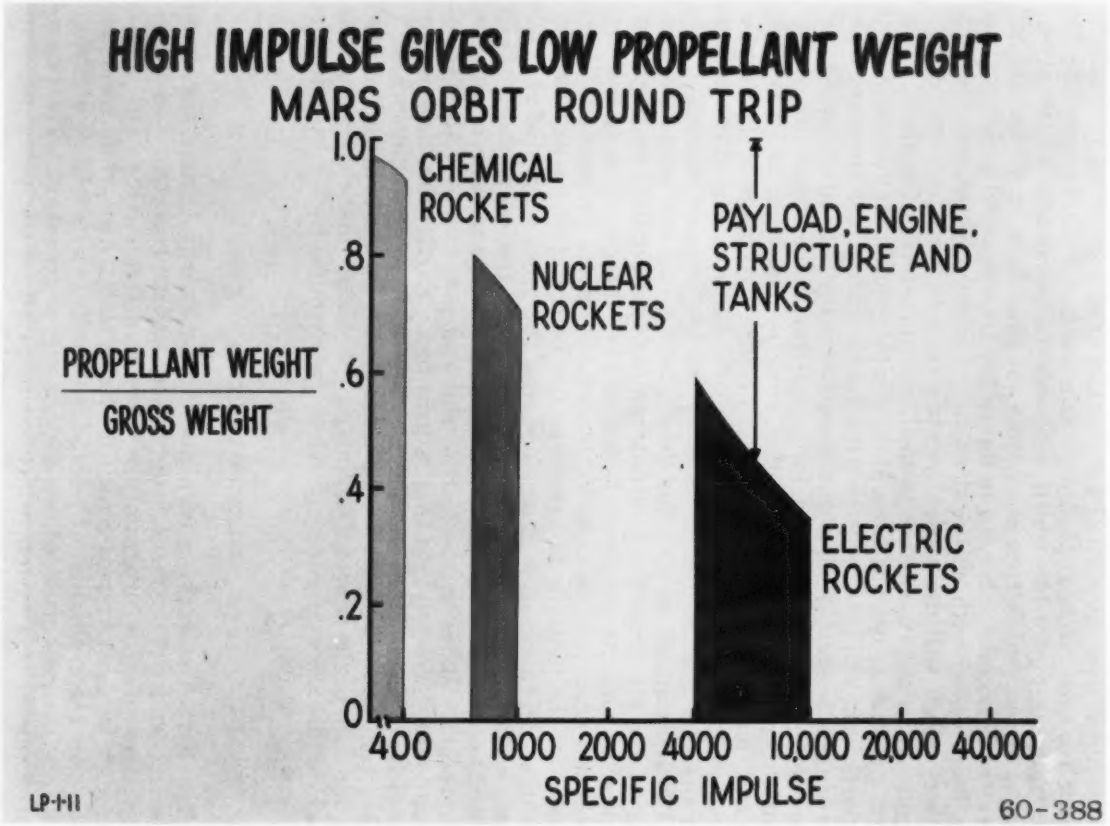

HIGH IMPULSE GIVES LOW PROPELLANT WEIGHT
MARS ORBIT ROUND TRIP
PROPELLANT WEIGHT / GROSS WEIGHT
1.0
.8
.6
.4
.2
0
CHEMICAL ROCKETS
NUCLEAR ROCKETS
PAYLOAD, ENGINE, STRUCTURE AND TANKS
ELECTRIC ROCKETS
400
1000
2000
4000
10,000
20,000
40,000
SPECIFIC IMPULSE
LP-111
60-388

FIGURE 146

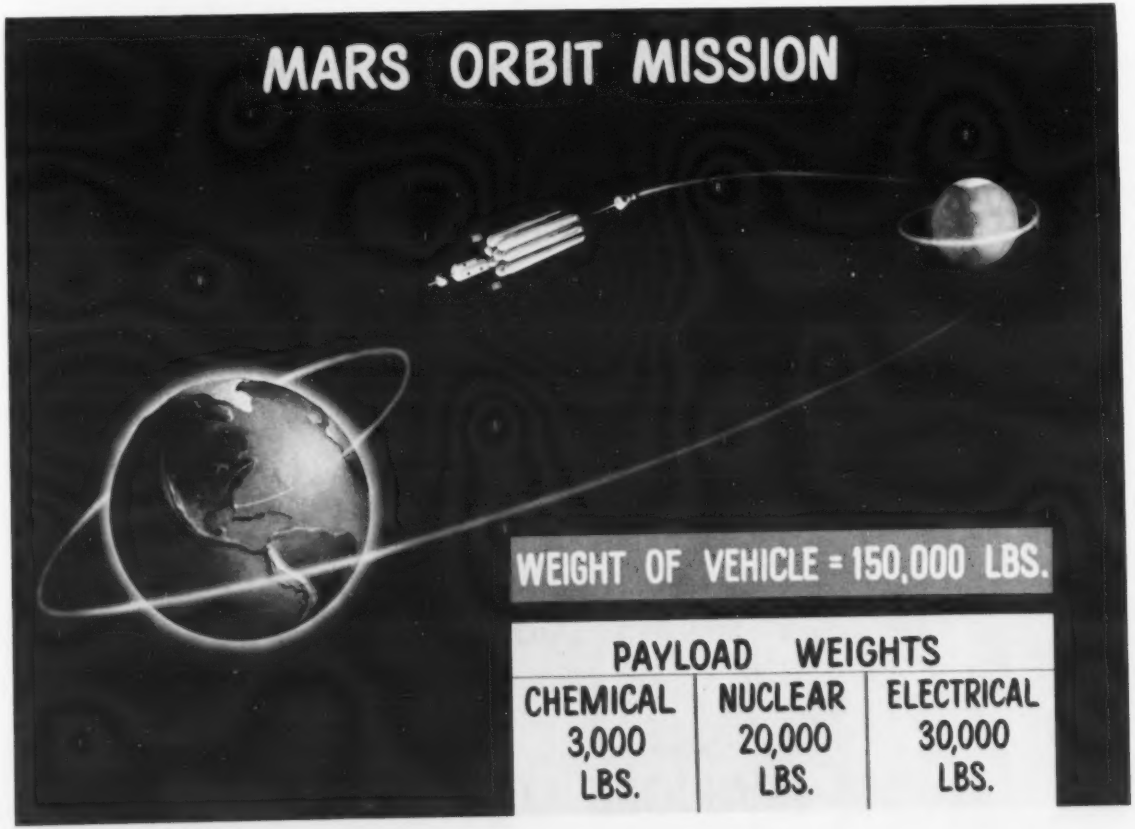

MARS ORBIT MISSION
WEIGHT OF VEHICLE = 150,000 LBS.
PAYLOAD WEIGHTS
CHEMICAL
3,000
LBS.
NUCLEAR
20,000
LBS.
ELECTRICAL
30,000
LBS.

FIGURE 147

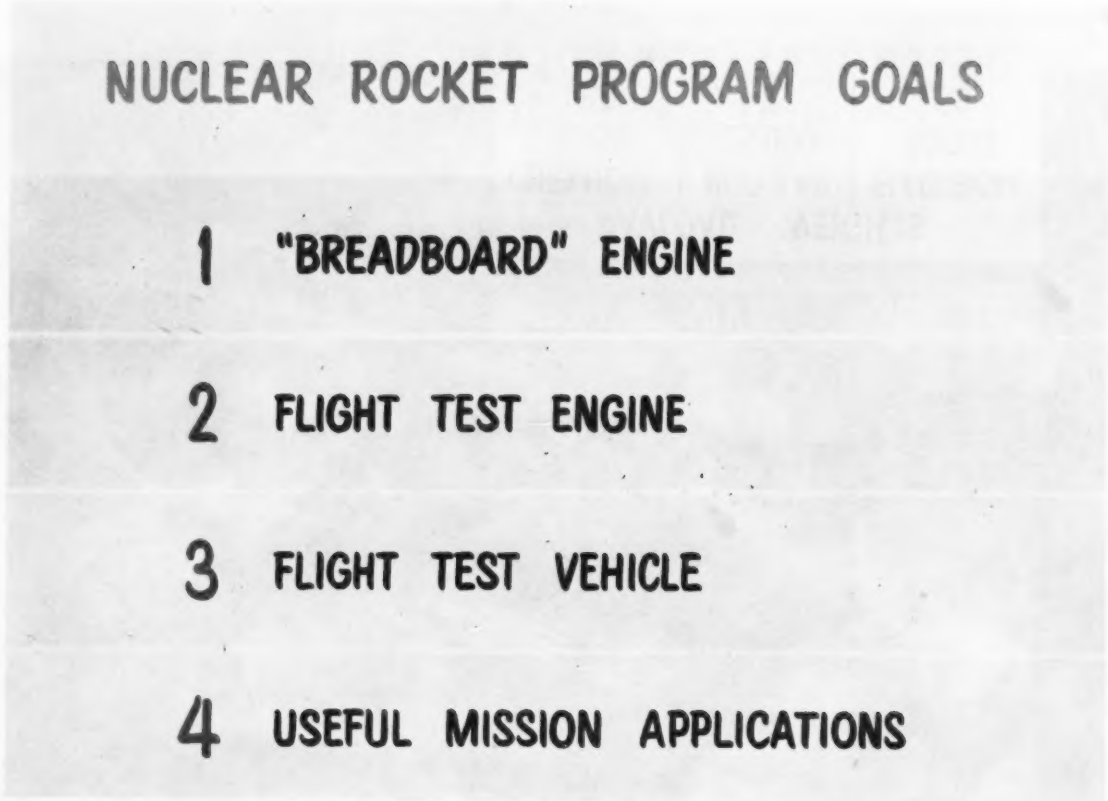

NUCLEAR ROCKET PROGRAM GOALS
1 "BREADBOARD" ENGINE
2 FLIGHT TEST ENGINE
3 FLIGHT TEST VEHICLE
4 USEFUL MISSION APPLICATIONS

FIGURE 148

AEC supplying reactor support. The NASA is responsible for developing a flight test engine, the flight test vehicle system, and for application of the nuclear rocket to those missions for which it may be particularly well suited.

The first step in achieving the breadboard engine goal was accomplished just this past summer when the Los Alamos Scientific Laboratory tested the research reactor called the KIWI–A at the AEC Nevada test site. This reactor is shown in figure 149 on its railroad test car. The reactor was moved by remote control from the assembly building to the test cell and after testing it was remotely moved back to be disassembled. The reactor was fired upward in order to simplify the test installation. The jet nozzle which is shown here in the chart was cooled by water for this test. The propellant used was gaseous hydrogen supplied from a gas storage tank farm. The gaseous hydrogen propellant and the water-cooled nozzle were used in order to simplify the test facility and the test operations so that the required reactor information could be most easily obtained.

The follow-on steps to this KIWI–A reactor test will be aimed at a logical development of the breadboard engine, including all of the principal components of the nuclear rocket shown in figure 145 (p. 826). The breadboard engine will include a reactor, propellant tank, liquid hydrogen turbopump, a liquid hydrogen cooled jet nozzel, and an automatic controls system that will simultaneously control the reactor and all of the flow system. These major components will not necessarily be packaged or positioned as would be required of a flight system such as the one indicated here.

As indicated earlier, NASA is supporting the breadboard engine development by developing certain nonnuclear components. NASA is developing, or will develop, all of these nonnuclear components shown on the chart. We are now funding the development of a suitable turbopump. This industrial development of the turbopump is backed up by a research program at our Lewis Research Center aimed at improving pump design methods and supplying data needed to improve turbopump performance. In addition, we are, during this fiscal year, initiating the development of a liquid-hydrogen-cooled jet nozzle to be used in the reactor test program.

This integrated AEC-NASA program will continue through the development of the flight test engine, development and operation of the flight test vehicle, and finally, the application of nuclear rockets to useful missions. Design studies are now underway at NASA and will be initiated in private industry to evaluate the best methods of flight testing nuclear rocket systems.

FLIGHT TESTING

One possible flight test configuration is shown in figure 150. In this case, the two-stage Saturn vehicle is used to boost a nuclear rocket stage into an earth orbit. After the stage is in orbit it could be started up and tested under conditions that simulate the conditions that would be encountered in accomplishing a useful long-range mission. Such an orbital nuclear rocket stage could be a comparatively low-thrust, low-reactor power system. For example, on the Saturn vehicle, a reactor power of 200 megawatts would be sufficient for this

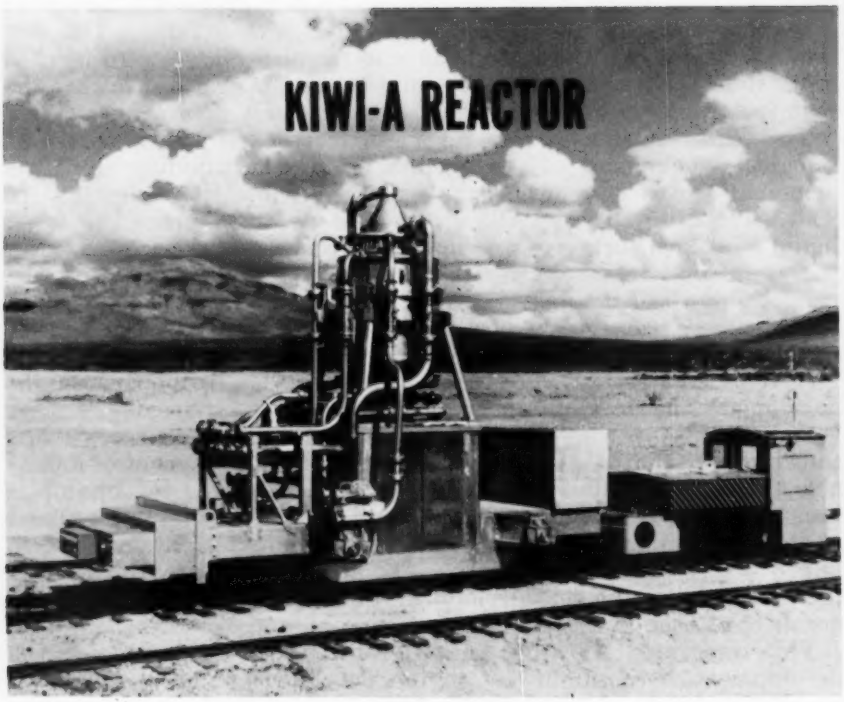


FIGURE 149

FIGURE 150

flight test. However, if we are to apply nuclear rockets as second stages rather than orbital stages, and if we are to apply them for useful missions to larger vehicles than the Saturn, then significantly higher powers will be required.

In conclusion, the large potential performance capability of the nuclear rocket requires that it receive important consideration in the space program and that it proceed as rapidly as possible on the basis of a sound technological approach.

VI. RESEARCH PROGRAMS

ENTRY INTO PLANETARY ATMOSPHERE

By Dr. Dean R. Chapman, Research Scientist, High-Speed Research Division, NASA Ames Research Center, Moffett Field, Calif.

The subject covered here is the entry of manned-space vehicles into some of the various planets. This is just one of at least five or six of what you can call major problem areas that are associated with manned-space flight, inasmuch as any of these manned missions—even if it is just to the Moon and back, let alone to any of the planets and back—are in the future.

PROBLEMS OF ATMOSPHERE REENTRY IN TERMS OF HEATING AND DECELERATION

When we compare the reentry problem for a manned spaceship with the reentry problem for either the ICBM or a satellite, there are several important differences. One is purely a quantitative difference. The spaceship enters the atmosphere faster. That is, it falls from much greater distances to the planet than either the satellite or the ballistic missile does, so it comes in faster. In fact it has about twice the kinetic energy that the satellite has. But apart from this purely quantitative difference there is a much more important qualitative one, and it concerns the guidance. There is an interrelationship between the guidance problem and the reentry heating problem and the reentry deceleration problem for the manned spaceship, which relationship we have not had to contend with before, and which is new to us.

If we have a ballistic missile, and instead of going to exactly the target, suppose it overshoots it by say 50 miles, or undershoots it by 50 miles. This doesn't make any difference to the reentry heating. It is just about the same and it does not make much difference to the decelerations, so the reentry problem and guidance problem in that sense are not connected. But for the space vehicle, if this overshoots its intended trajectory coming into the planet by 50 miles or undershoots it by 50 miles, this can be catastrophic as far as the accelerations are concerned to an occupant in this ship and, also, the heating problems with this slight error in guidance can be very much different.

All of these problems of reentry heating and deceleration can be completely eliminated if it were practical to use the technique of rocket braking illustration on (fig. 151), which technique was thought of and described at least 100 years ago by a lot of far-thinking, science fiction writers, including Jules Verne. The idea is that in approaching the planet the rocket thrust is just turned on in a

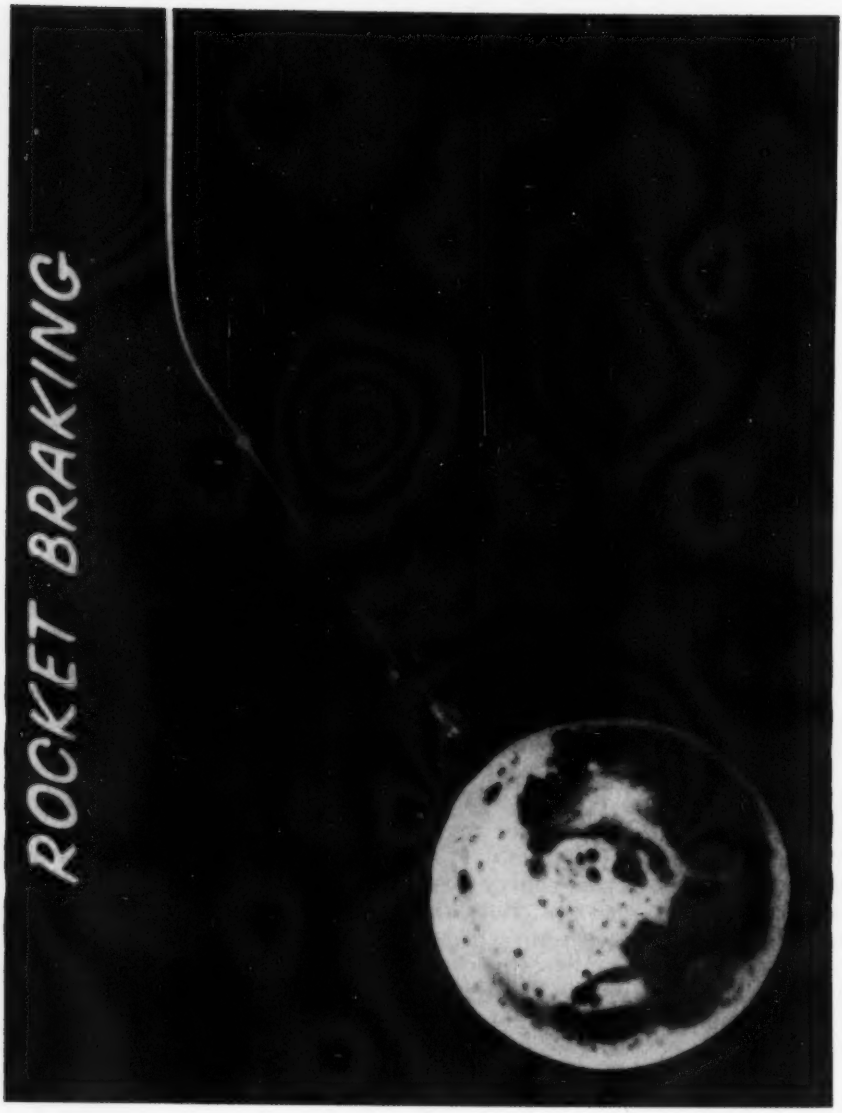


FIGURE 151

reverse direction so that the vehicle slows up before it gets to the outer edge of the atmosphere. This would eliminate the problem. But the only catch is that it takes so much fuel to be burned in slowing up the vehicle for a planet like the Earth that it would be very costly in weight.

We would have to build the entire vehicle about 50 times as large, so we would rather take the reentry problem, solve the reentry problem, than we would build a vehicle maybe 30 to 50 times as large. One method of using the air to slow the vehicle down instead of the fuel, which has been considered for about 30 years and which looked very attractive until recently, is the multiple-pass atmosphere braking. This idea is that the spaceship comes in at a trajectory, as shown in figure 152, and it passes once just in a grazing sense to the edge of the atmosphere, slows down a little and tightens the orbit, and then repeats the procedure.

In this way the slowing down is done in steps and is nice from the reentry heating and deceleration viewpoint. But the problem, of course, one of them, is that the vehicle must pass several times through the radiation belt which is undesirable if for no other reason it would impose a severe weight penalty for us.

So the type of entry that is being considered most seriously is a single-pass type wherein the space vehicle enters again along some trajectory and on the first pass it enters the atmosphere and lands.

For a comparison, there is illustrated in figure 153 also the nearly circular trajectory of the manned satellite capsule. You will notice the manned satellite capsule avoids the radiation belt by orbiting between the Earth and the inner radiation belt.

Now, the spaceship has to avoid, or can avoid, the radiation belt by the proper guidance and the proper path. Actually this problem of avoiding the radiation belt is very easy compared to the guidance problem of hitting a certain entry corridor which the space vehicle must hit and which is illustrated in figure 154.

This figure illustrates different possible approaches to trajectories. If we happen to overshoot too much and approach along a trajectory—that is, one of the two outer dotted trajectories—the vehicle will pass too far away from the planet, too high in altitude, so that there is no air out there and no atmosphere to slow you down, so it just goes around and keeps on going and doesn't land.

Now, on the other hand, if the vehicle comes in too close, undershoots too much, it will intercept the atmosphere at such a steep angle that the impact will result in decelerations that are too large for a human occupant. So, by the time you rule out all of these areas, all we are left with is a narrow entry corridor down through which the vehicle must be guided in order to have enough drag on the one hand to land and in order not to have too much to result in too large decelerations.

NARROW REENTRY CORRIDOR IMPOSES SEVERE GUIDANCE REQUIREMENT

One of the points to be considered concerns the narrowness of this entry corridor. The width of the corridor at the neck for the Earth's atmosphere for any nonlifting or bulletlike or nose-cone-like object is only 7 miles wide.

53795 O—60—pt. 2——18

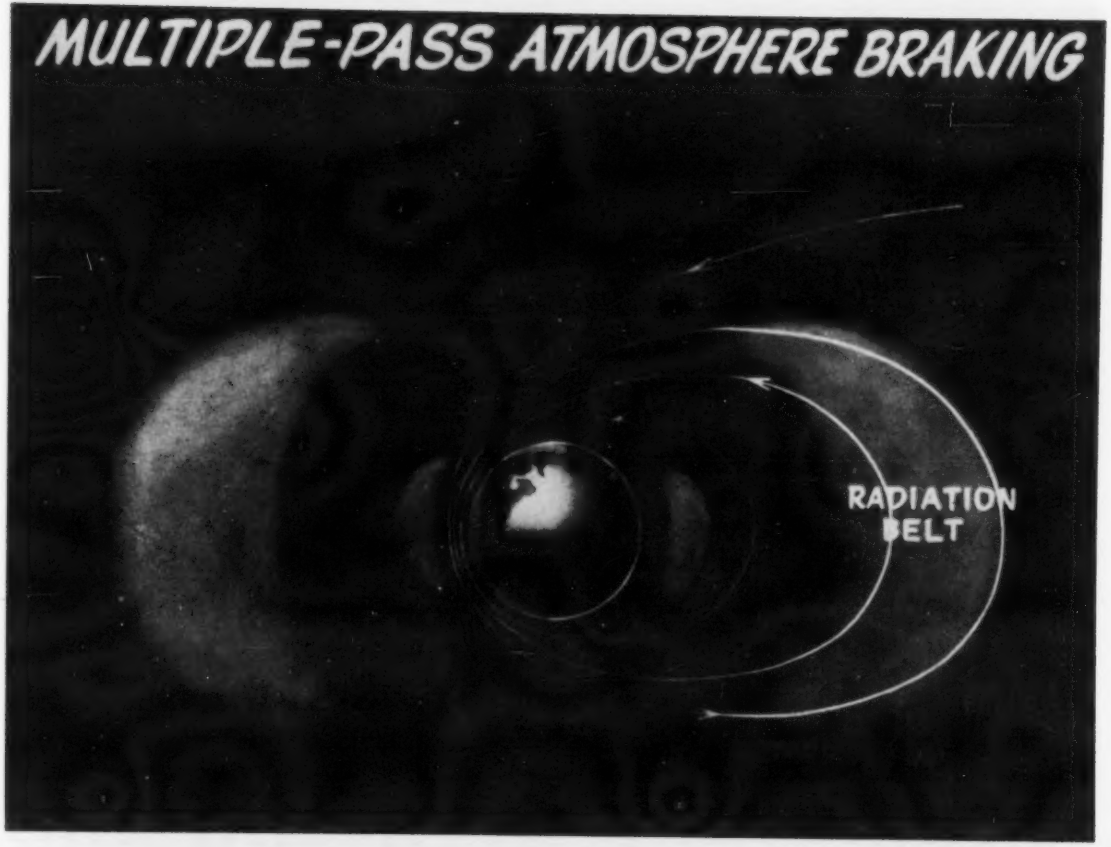

MULTIPLE-PASS ATMOSPHERE BRAKING
RADIATION BELT

FIGURE 152

SINGLE PASS ENTRIES

FIGURE 152

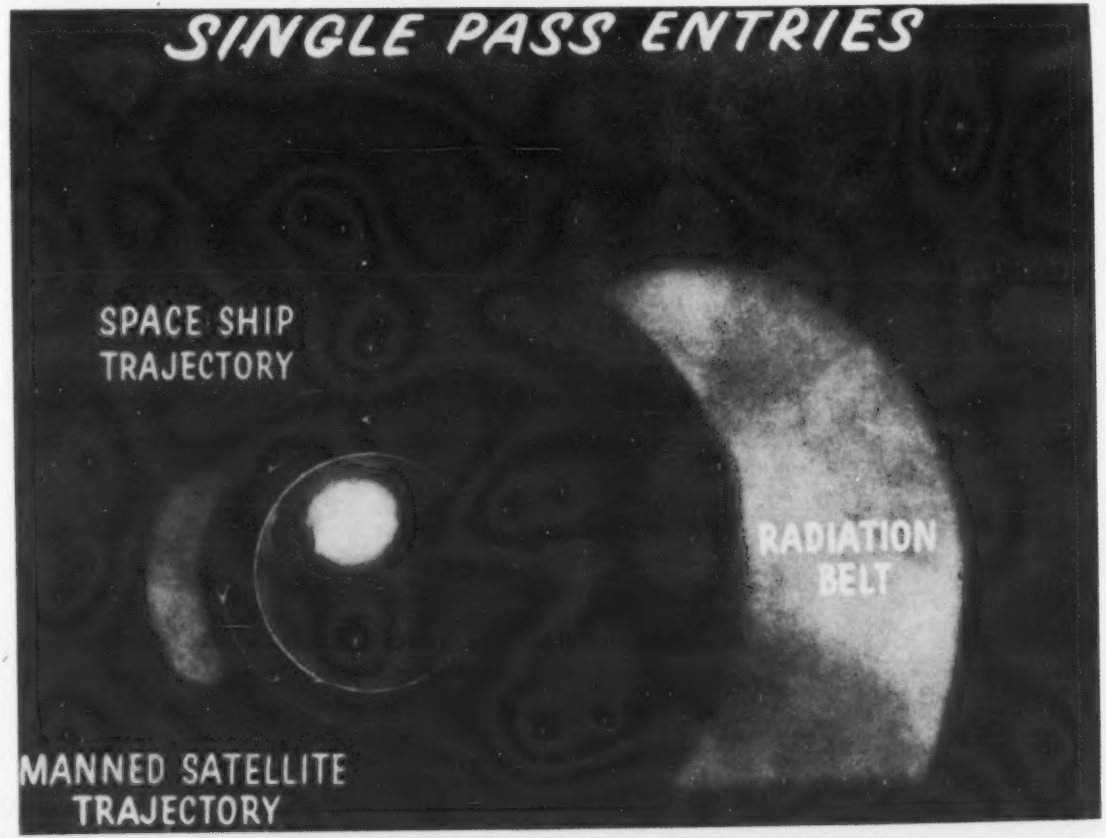


FIGURE 153

GUIDANCE PROBLEM FOR MANNED SPACE SHIP
TOO LITTLE DRAG
ENTRY CORRIDOR
TOO LARGE DECELERATION
W
CORRIDOR WIDTH W
7 MILES
60 MILES

FIGURE 154

If we make a much more complicated vehicle, a lifting vehicle which can maneuver both through angle of attack as well as laterally, the corridor can be extended to about 60 miles, which is a much easier guidance problem, but still difficult.

The penalty that we would have to pay, is the complexity of a lifting vehicle compared to a nonlifting one. We can think of the lifting vehicle, for example, as a supersonic airplane and the nonlifting as a bullet.

It has taken more research and development to develop the supersonic airplane than it has the bullet, and by the same token it is going to take a lot more research, development, effort, and time, to develop a lifting manned spaceship than it has taken to develop a nonlifting ballistic vehicle.

An illustration will show roughly the degree to which this presents a problem. Even with the lifting vehicle where the corridor width is 60 miles, this is small compared to the diameter of the planet, 8,000 miles for the earth. This 60 miles is a little less than 1 percent of the earth's diameter.

The skin on an apple is a little less than 1 percent of the apple's diameter. So this guidance problem of hitting this entry corridor is just about the same guidance problem that William Tell would have had, that is, if he had had to shoot the skin off the apple instead of just hitting the apple. Now that sounds like a rather severe guidance requirement, and it is. It is a very difficult one, but certainly not impossible.

Figure 155 illustrates for purposes of orientation what the entry corridors look like for Venus and also for Mars—they are quite different for the different planets.

These are roughly to scale. For the Earth and Venus it is the narrow white corridor as illustrated, but for Mars the entry corridor, the white part, is much broader. When we consider other objects in the solar system we encounter even more diversified extremes.

COMPARISON OF AERODYNAMIC HEATING PROBLEMS OF SPACESHIP AND BALLISTIC VEHICLE

In figure 156 there is illustrated the aerodynamic heating problem that would be encountered for a spaceship of this type by comparing this with the aerodynamic heating problem for the ICBM, and also the manned satellite; what is shown is the rate at which heat energy is poured into these vehicles as a function of the time that has elapsed after the entry started. The ballistic vehicle, the ICBM, encounters a very intense heating rate but only for a few seconds, 10 seconds or so.

In contrast, on the right in figure 156, is a spaceship which encounters much lower heating rates, but must endure them for much longer times. Actually this can result in a more severe heating problem. An example here, we can think of by imagining that in one part of a room we have a flame that is very intense and on the other side of the room we have a pan of boiling water. If we put a glove on our hand and go over to the flame, even though it is much hotter than the boiling water, and pass our hand through it for a few seconds and we only have to endure it for a few seconds and take it off, the glove will protect us and our hand won't be burned.

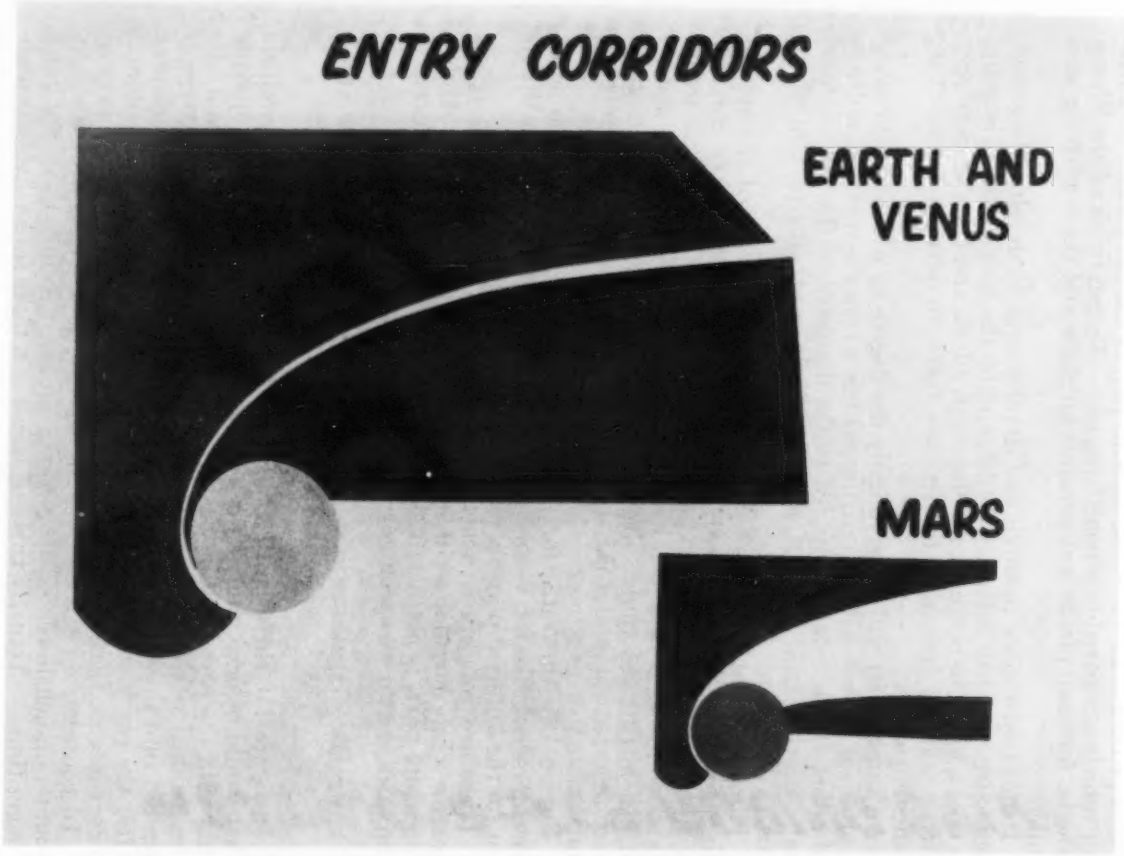


FIGURE 155

FIGURE 155

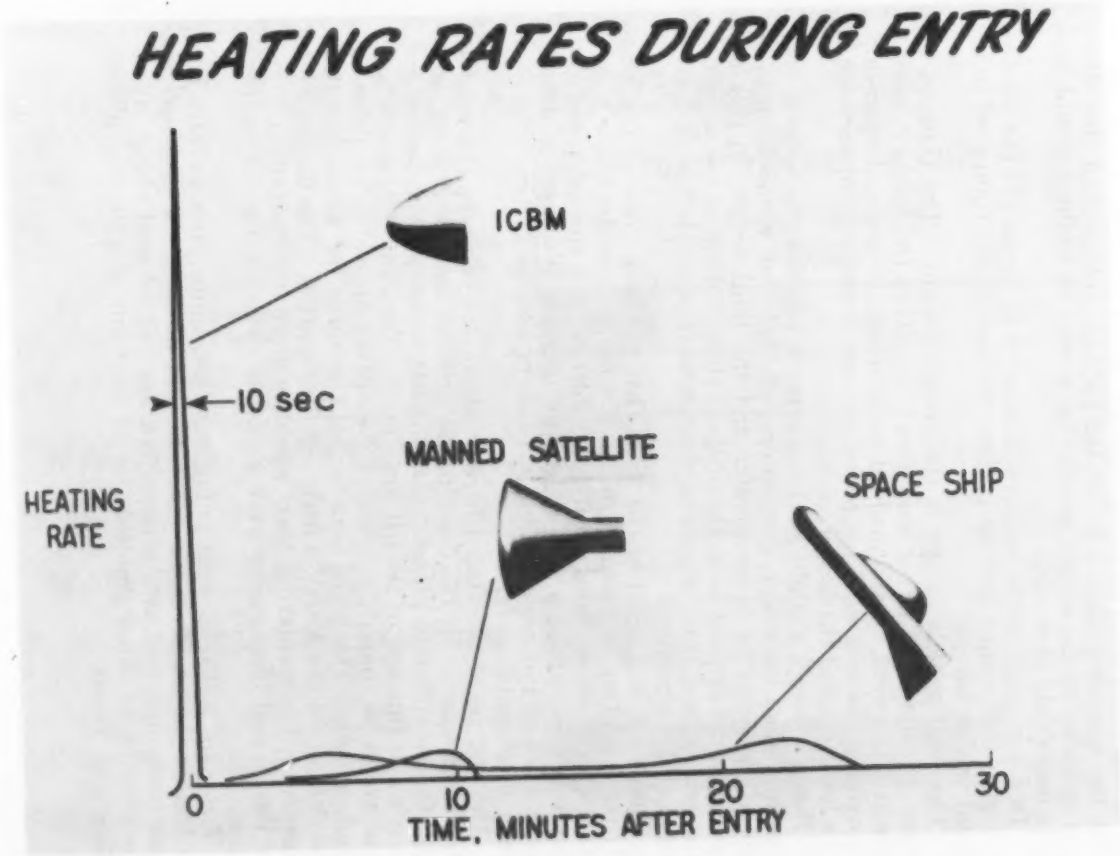


FIGURE 156

But if we place this same hand in the same glove in the boiling water, even though it is not nearly as hot as the flame, and have to endure it and leave our hand there for 20 minutes, we can clearly get burned.

In some respects this aerodynamic heating problem is more severe for the spaceship than it is for the ballistic vehicle, and this shows up in terms of the weight which the current technology would have in a heat shield protection.

In a bar graph form we have illustrated in figure 157 the relative weights that would have to go into the heat shield compared to the total vehicle weight.

The total vehicle weight is the overall weight. The fraction for heat shield weight is not very great for either the ballistic missile, about 25 percent, or the manned satellite, or the manned spaceship, providing the spaceship happened to come in near the undershoot or the lower limit of that entry corridor.

But if through a slight guidance error it happened to come in near the overshoot boundary, the amount of heat that would have to be absorbed would be much greater and the total weight in the heat shield would amount to on the order of three-fourths of the weight of the vehicle and this, of course, doesn't leave much left over for the payload or structure.

The point is that all of the work that has been done on the aerodynamic heating problem for ballistic missiles provides for us a good start on the aerodynamic heating problems for a spaceship but does not solve the problem for us by any means. We need to develop more efficient and more flexible methods of heat protection than have been developed thus far.

The last point illustrated here in figure 158 concerns the relative degree of severity of the deceleration problem and the heating problem for the different planets. On the left is charted the deceleration in g.'s as a function of the lift-drag ratio. Zero would be a nose cone, one would be roughly a spaceship, a lifting spaceship at about the angle shown. The point here is that the curve for Venus is a little lower than for the Earth, a little less deceleration. The decelerations encountered in reentering Mars would be much less than either Venus or Earth, and likewise we have a similar situation for the temperatures.

The point is that, at least as far as we know now, once we learn how to handle the aerodynamic problems and deceleration problems for reentering into our own atmosphere, we will be well along toward the solution of those problems for at least our neighboring planets, Mars and Venus.

RELATIVE HEAT-SHIELD WEIGHTS

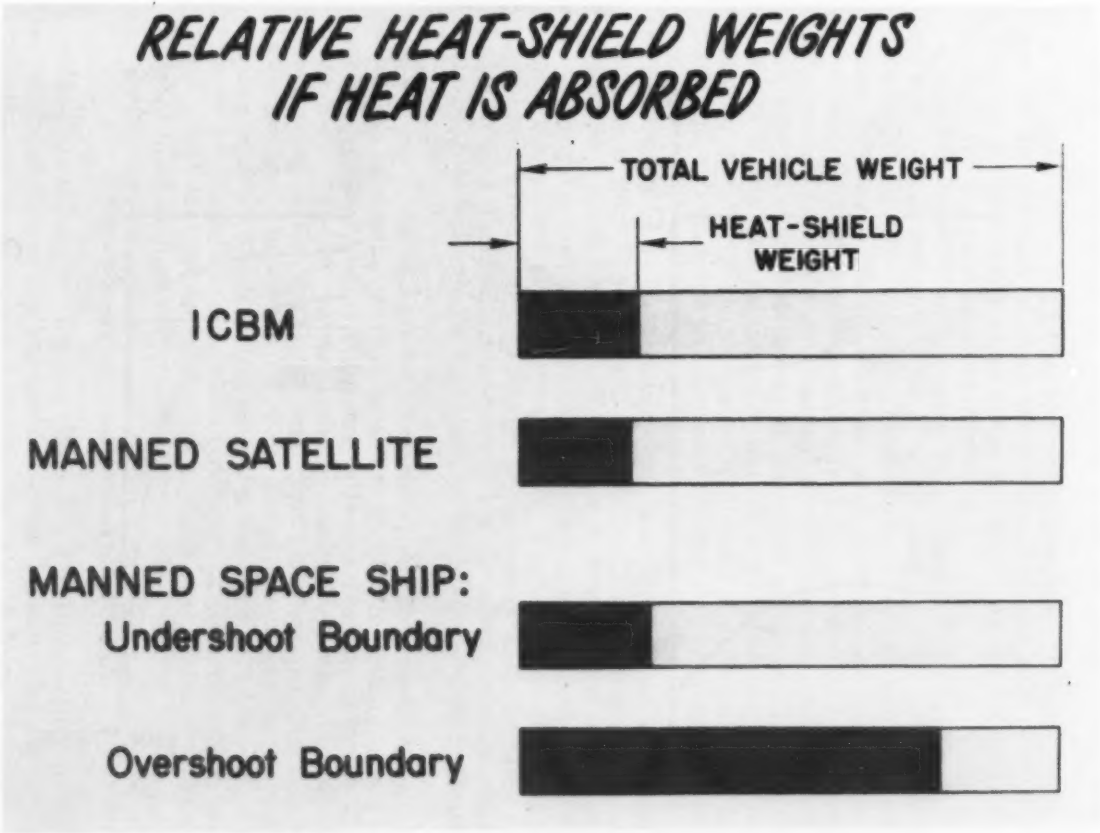

RELATIVE HEAT-SHIELD WEIGHTS
IF HEAT IS ABSORBED
TOTAL VEHICLE WEIGHT
HEAT-SHIELD WEIGHT
ICBM
MANNED SATELLITE
MANNED SPACE SHIP:
Undershoot Boundary
Overshoot Boundary

FIGURE 157

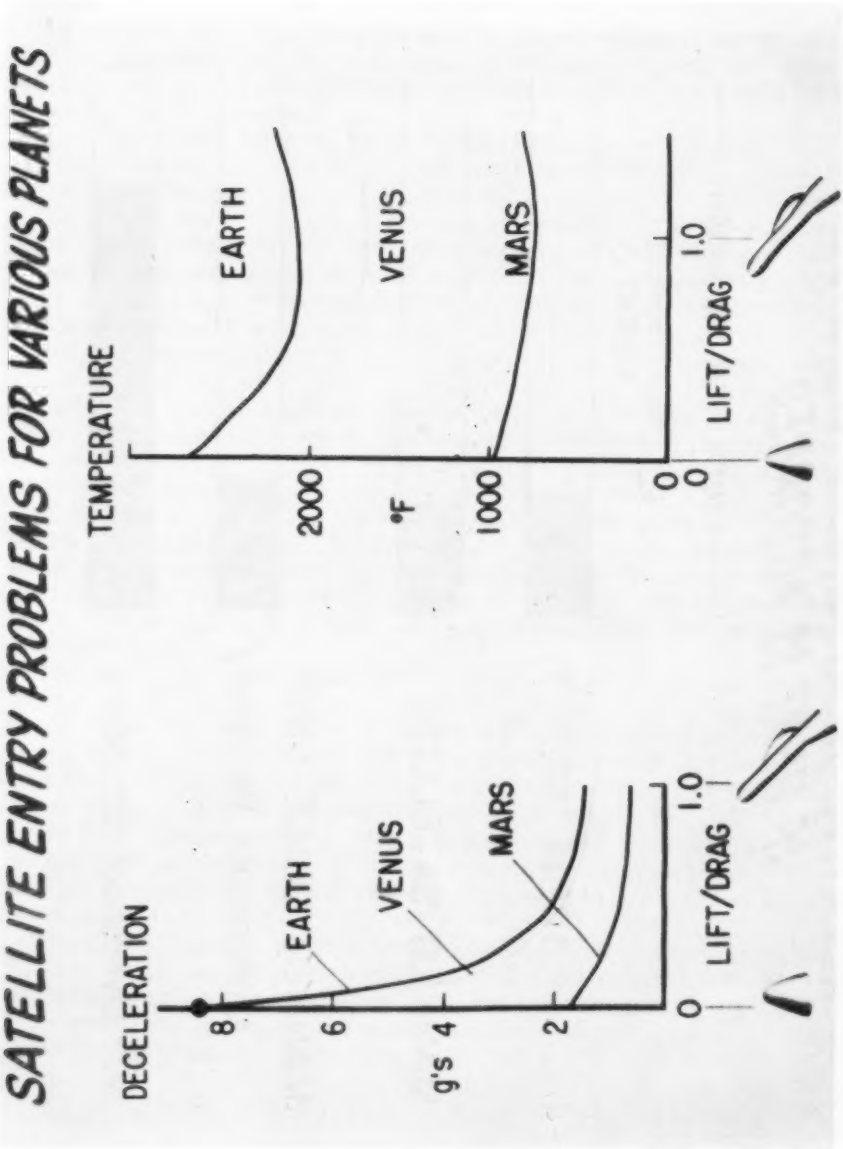

SATELLITE ENTRY PROBLEMS FOR VARIOUS PLANETS
DECELERATION
g's
8
6
4
2
0
EARTH
VENUS
MARS
LIFT/DRAG
1.0
TEMPERATURE
°F
2000
1000
0
EARTH
VENUS
MARS
LIFT/DRAG
1.0

FIGURE 158

MATERIALS RESEARCH

By G. Mervin Ault, Assistant Chief, Materials and Structures Research Division, NASA Lewis Research Center, Cleveland, Ohio

It is generally agreed that the achievements in materials research are the foundations of much of the development related to flight. This progress depends upon achievements of the kind of materials we need for the particular environments.

Materials research is emerging as a science, and as a result new materials are being developed at an increasing rate. Many of the materials that are relatively commonplace today, and that have opened new vistas for the designer, were virtually unknown 10 to 15 years ago. An outstanding example of this is afforded by transistor materials. The recent development of this material has ushered in new concepts in the vital areas of electronic component miniaturization, reliability, and power reduction for communication. Similarly titanium and beryllium are recently developed materials that have made and will continue to make possible major reductions in aircraft and spacecraft weight. Still another example is the case of the refractory metals. Molybdenum was used largely as an alloying addition to steel 10 years ago. Today many missiles are operating at advanced conditions because they have molybdenum components. The other refractory metals, although lagging behind molybdenum in development, have steadily progressed. Today there are numerous columbium alloys being produced commercially and tantalum and tungsten and their alloys are available in pilot plant quantities. None of these, columbium, tantalum, or tungsten, were on the market 5 years ago.

These examples indicate that materials research is meeting the challenge and producing positive results at an ever increasing rate. Despite this the urgency for further advances has grown rather than diminished. Today, for example, if better high temperature materials were available, the performance of the turbojet engine could be immediately improved. The successful achievement of a useful nuclear powered airplane and nuclear rocket awaits the development of superior materials. If future objectives of aeronautics and space flight are to be met, an aggressive expanding program of materials research must be pursued.

ENVIRONMENTAL DEMANDS ON MATERIALS

Materials are chosen for use on the basis of their ability to withstand the environments and thus it is first necessary to define their end uses. If possible, available materials will be used. If materials are not available to meet the environment of the intended application, the research on modifying existing materials and exploring new materials begins. The environments of materials of special interest to NASA are those imposed by:

(*a*) Propulsion devices for aircraft, missiles, and spacecraft.

(*b*) Devices for generation of electric power for space vehicles (turboelectric and direct conversion).

(*c*) Heat sources in addition to combustion (e.g., nuclear reactors and solar collectors) for both (a) and (b).

(*d*) Structures of missiles and spacecraft.

(*e*) Space itself (i.e., hard vacuum, radiation, and meteoroids).

The achievement of the desired materials requires effort along all avenues that hold promise.

Because of this very broad spectrum of end uses, it is necessary to generalize these environments insofar as possible and then to generalize the materials research.

TEMPERATURE RANGES

Devices have been designed to impose temperatures of from −423° F. (for tanks for the hydrogen propellants of the chemical and nuclear rockets) to in excess of 5,000° F. (for structures of reentry vehicles and rocket motors). At very low temperatures the more difficult problems are associated with finding high strength-to-weight ratio materials to permit the very large propellent tanks to be made of minimum weight. Fortunately most materials tend to increase in strength as the temperature is decreased from room temperature to the temperatures of liquid hydrogen but unfortunately many materials lose their ductility at these low temperatures; some metals then have a brittleness approaching that of glass. Microscopic flaws in tanks produced of such materials have resulted in catastrophic unpredictable failure. Significant contributions have been made within NASA laboratories on similar problems for the casing (or tank) of the solid propellent rocket and this research is now being extended to the cryogenic tank problem. It now appears that we will have to seek materials having unique combinations of strength, ductility, and weldability. The evidence would indicate that significant improvements are possible.

CORROSION

Materials to resist the severe corrosion and erosion environment of most of the mentioned powerplants and aircraft structures have been the subject of continuing research for several years. Recently, however, the search for suitable methods of generation of electric power in space (for use in auxiliary power units or electric propulsion devices) has focused considerable attention on turbine-driven generators and important new corrosion problems. Conceptual studies indicate that the most attractive working fluids are liquid metals that are vaporized and expanded through a turbine in a manner analogous to the conventional ground-based steampower generation plant. For advanced turboelectric systems sodium, potassium, rubidium, and lithium operating at temperatures from 1,400° F. to greater than 2,000° F. (depending on the metal chosen) are of interest. Essentially no data are available to indicate what metals might contain these reactive metals in the liquid-vapor cycle at these temperatures. If metals cannot contain a suitable working fluid, advanced turboelectric systems will not be possible. This corrosion research then is an extremely important area of immediate research and initial facilities are now being installed at an NASA research center. The future of these power generator systems depend on the successful outcome.

SPECIAL-PURPOSE MATERIALS

Most materials described in these presentations have been structural materials—materials of interest because of their strength and corrosion resistance. Also of considerable importance are a wide variety of special purpose materials; lubricants, bearing materials, elastomers, fluids, transparent materials, and electronic and energy transforming materials. NASA has made important contributions in the more critical of these. For example, contributions to the field of lubricants and bearings for very high temperatures have been made over a period of several years and the lubrication research is being extended to study the influence of the space environment. The hard vacuum of space causes the evaporation of lubricant films and thus resulting in seizure and welding of surfaces that would remain lubricated on the ground. Although many of these problems can apparently be overcome by clever design approaches, a generally improved understanding of the deterioration of lubricant films in space is required.

Many of the special-purpose materials, for example, electronic materials such as transistors or semiconductors, are vitally important to many applications in addition to NASA's and are thus receiving considerable attention throughout the Nation. Some, however, such as energy transforming materials—thermoelectric and thermionic devices—for conversion of heat energy to electricity are of unique interest to NASA. Because these devices must be thrust into space, the need for minimization of the weight requires these systems when used in space to operate at much higher temperatures than is necessary for ground-based use. Vigorous study is needed to find efficient materials if the required large amounts of power are to be generated. This must be the subject of expanding research under NASA sponsorship.

HIGH TEMPERATURE MATERIALS

In general we have achieved the kinds of advanced powerplants we have today because we have had a preceding development of high temperature materials for some of the components of these engines.

However, even though we have a successful turbojet engine operating at high temperatures, the highest temperature to which parts are subjected in that engine at high stresses is about 1,800° F. It would be desirable for many of the advanced propulsion devices we consider, such as chemical rockets and nuclear rockets, to extend use temperatures to 5,000° and 6,000° F.

Now the backbone of the jet engine has been the nickel and cobalt base superalloys. If we are to get to much higher temperatures, we have to start emphasizing other kinds of materials. The reason for this is that the nickel and cobalt base materials, as shown here, melt at temperatures of about 2,700° F. Obviously if we want to go to much higher temperatures, then we must use new kinds of materials that melt at much higher temperatures. One point of figure 159 is to indicate that there are quite a wide variety of materials available to us for study.

We usually prefer to use metals, because they are ductile; they can be bent and they can be formed. Fortunately, there are a few refractory metals available, as indicated here. Wherever we have an arrow

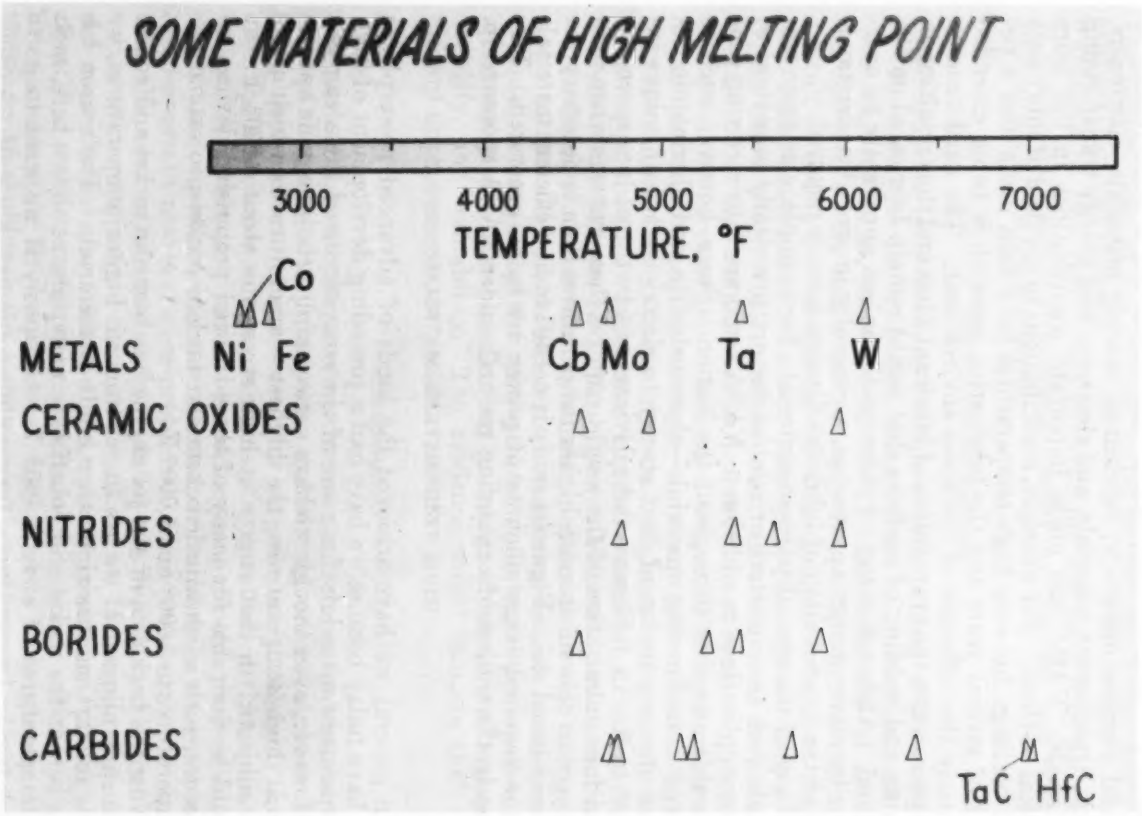

SOME MATERIALS OF HIGH MELTING POINT
3000
4000
5000
6000
7000
TEMPERATURE, °F
Co
METALS
Ni
Fe
Cb
Mo
Ta
W
CERAMIC OXIDES
NITRIDES
BORIDES
CARBIDES
TaC
HfC

FIGURE 159

it indicates the presence of that material. We have columbium, molybdenum, tantalum, and tungsten. Tungsten has the highest melting point and melts at about 6,100° F. The materials shown below here by just the arrows are a different class and they might be characterized by calling them ceramics inasmuch as they are about as brittle as glass. These are the compounds of metals, the oxides, nitrides, borides, and carbides of metal.

The highest melting point material we know is hafnium carbide that melts at over 7,000° F. The important problems with these materials is that we have to change our technology. There is a more difficult problem in trying to melt tungsten at 6,000° than in trying to melt and fabricate these other materials that we are used to at around 2,400 to 2,600° F.

Within the laboratories of NASA we can currently melt tungsten. We are working with this metal and the highest melting of these ceramics. We are learning to fabricate them, to shape them, and to produce them in forms that we can use for our research. In addition to having extended our whole technology of working with materials by going to extremely high temperatures we have had to develop the techniques for testing these materials at these temperatures. We now can test routinely at Lewis Research Center up to temperatures of 4,500° F.

PROPERTIES OF HIGH TEMPERATURE MATERIALS

FIGURE 159

Figure 160 indicates some properties of these materials at high temperature. The figure indicates that not only do these new materials have high melting points but they do have good strengths at high temperature. This is a plot of strength of the materials against temperature in degrees Fahrenheit, and generally the strength falls off in any material as we go up in temperature. This shows the strength of the best of the steels, the best of the nickel or cobalt base superalloys, and some data we have obtained for pure tungsten.

This would indicate that if we needed a strength of 10,000 pounds per square inch, tungsten would have a temperature advantage of the order of about 1,500 to 1,600° F. over our best nickel and cobalt base alloys. As we continue our research and try to strengthen tungsten, which is a metallurgical problem, we should raise these strength levels appreciably. So it looks like we have before us a class of materials that will have good strength at very high temperatures.

There will remain many problems in using these materials, even when we have them developed. Tungsten is about twice as heavy as nickel or cobalt. That means we have to limit its use in space vehicle propulsion systems. Another disadvantage is that tungsten oxidizes very rapidly. So it would be quite impossible to use tungsten in air. This is also true of most of the refractory metals at high temperatures in an environment of air. It is thus an important area of research to find out how to coat or protect these metals or to alloy them in some way so that we can use them in air at high temperatures. However, they are of considerable interest for other environments. For instance, in the chemical rocket or the nuclear rocket, the environment is not air.

If we are to make great strides in going to higher temperatures that we need for many of our propulsion devices today, we are going to have

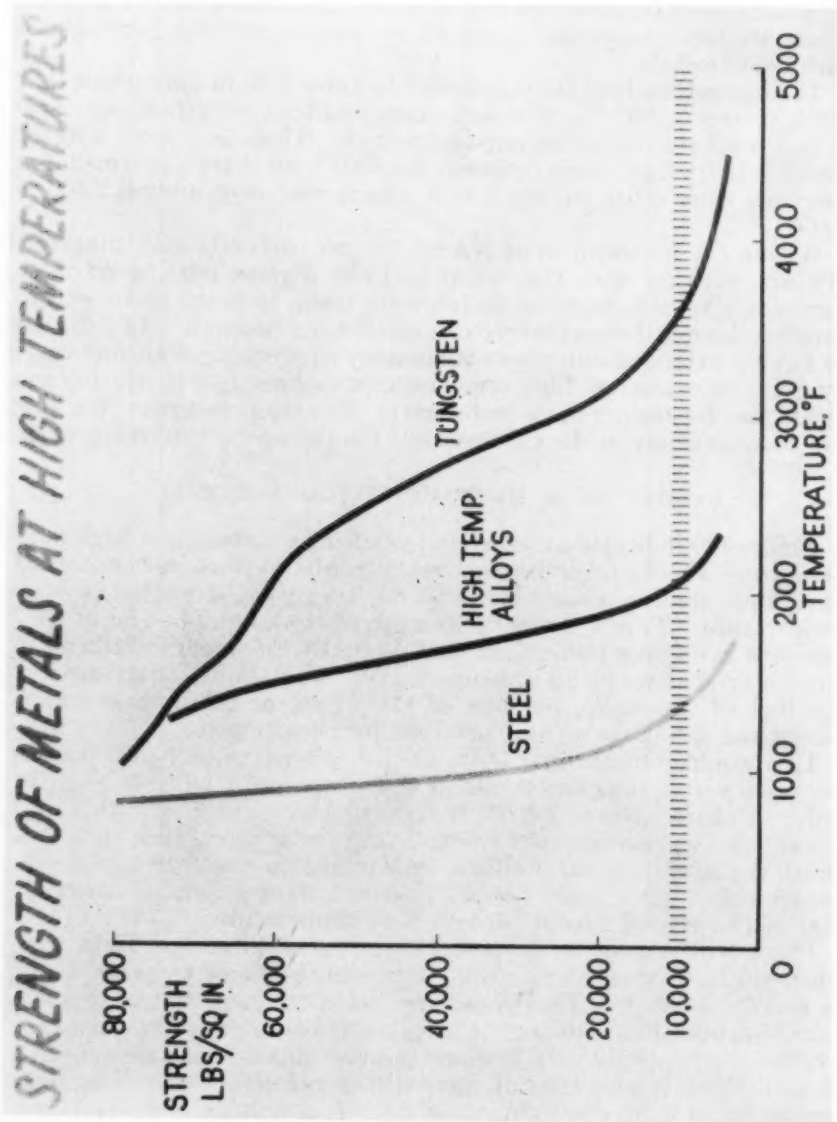

STRENGTH OF METALS AT HIGH TEMPERATURES
STRENGTH LBS/SQ IN.
80,000
60,000
40,000
20,000
10,000
0
1000
2000
3000
4000
5000
TEMPERATURE, °F
TUNGSTEN
HIGH TEMP. ALLOYS
STEEL

FIGURE 160

to look at new classes of materials and extend our whole technology in materials research. Another problem we are comforted with is the action of materials in the new environments of space. What will happen to materials in space? The kinds of environments that concern us are low pressure, radiation, and the meteoroids indicated schematically by figure 161.

LOW PRESSURE IN SPACE

The low pressure problem comes about from the fact that, of course, we have in deep space a perfect vacuum, in other words nothing at all. Now this can in many ways be an asset. For instance we could make structures out of tungsten and use them in space. Electric light bulbs have tungsten filaments operating at 3,500° F. in a vacuum or in a neutral atmosphere.

Thus, a host of new materials might be used at high temperatures in space. On the other hand, the problems that we encounter are generally due to this low pressure phenomenon. We are familiar with the fact that liquids evaporate very rapidly, and as we raise the temperature they go off more rapidly. Solids evaporate too. The problem is that the atoms leave the surface at a very rapid rate at high temperatures.

For example, if we were to use a space radiator of, say, 0.020 inch thick nickel at 1,900 ° F.—to take an extreme example—we would lose half thickness in 1 year.

Now for many applications we would like to use materials for much longer than that. In the case of metals there are solutions to this problem. In the case of plastics that we might like to use in space or some of the ceramic compounds this is a serious problem that needs much more research and understanding before we will know which of these materials can be used to fabricate high temperature space vehicles and components.

FIGURE 160

RADIATION IN SPACE

Another problem is that posed by the radiation in space. This is indicated schematically again in figure 161. Particles in space such as cosmic radiation and the electrons and protons of the Van Allen radiation can impinge on our materials. Another kind of radiation with which we are concerned is the ultraviolet from the sun. On earth we are protected from most of this radiation by our own atmosphere, but in space the intensities go up.

In present appraisals of that problem it appears that metal will not be particularly harmed by the kind of radiations that we will encounter in space. It is indicated that some of the plastic-type materials will be damaged, or transparent windows may be darkened, perhaps over a period of years by this kind of an environment. But there seems to be no reason that radiation should be a serious deterrent to space travel from the standopint of what it does to materials of construction.

FUNDAMENTAL MATERIALS RESEARCH

Fundamental research is also being done on the physics and chemistry of solids.

For generations metallurgy, the art of making materials, has been almost a static art handed down from generation to generation. It

53795 O—60—pt. 2——19

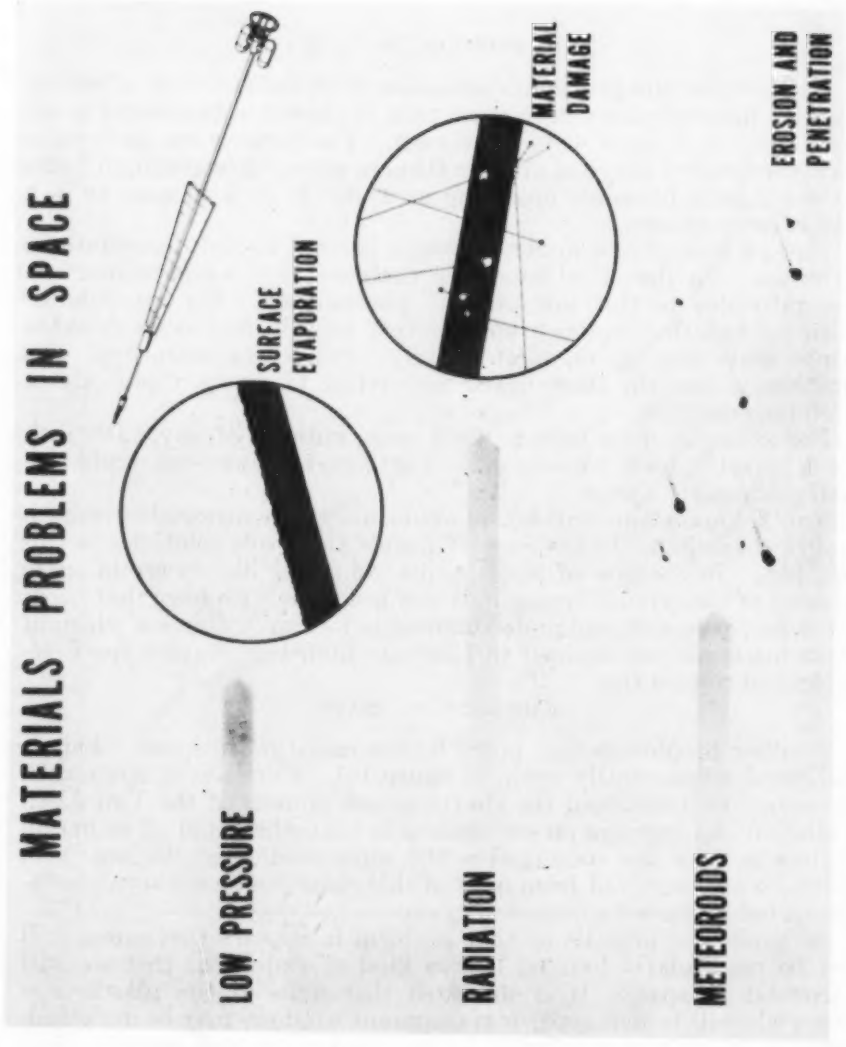

MATERIALS PROBLEMS IN SPACE
LOW PRESSURE
SURFACE EVAPORATION
RADIATION
MATERIAL DAMAGE
METEOROIDS
EROSION AND PENETRATION

FIGURE 161

has only been within the last 20 years that we have really begun to accept the fact that the properties of materials are dependent upon the arrays of atoms that make up the materials. Once we can build our materials research upon a foundation of science, then progress should certainly be more rapid.

For example, the theoretical physicist doing research in physics of solids many years ago calculated the theoretical strength of a material. What he did was consider it as rows of atoms, calculate what energy it would take to pull them apart and calcuated strengths for materials that were to 20 to 100 times as great as we ever achieved in real materials that we use for construction.

This has fostered a search for the kinds of materials that might really have this phenomenal strength. Figure 162 is a plot of the strength of pure iron down to the size of whiskers. What we show here is the strength on a unit basis, strengths in pounds per square inches of cross-sectional area against diameter of specimen.

Pure iron in large specimen sizes—bar stock size—might have strengths of the order of 40,000 to 50,000 pounds per square inch but as we go down in diameter we approach this material we now call a whisker: these are little fibers that have diameters much less than that of a human hair; we measure strengths of 2 million pounds per square inch.

So it has finally been found that there are some kinds of materials available that approach the theoretical strength calculated by the physicist. Several explanations for this strength have been proposed. One relates to the fact that in real materials we have imperfections in the atomic structure. If we have a row of atoms missing we call that a dislocation, and dislocations are sources of weaknesses in material. It has been shown that these little very delicate whiskers are perfect crystals, the first time in nature we found a perfect material and that is why we are getting phenomenally high strengths. Of course, it is a problem of applied materials research now to see how we can put these whiskers together to make structures, solid bodies that might have really very high strengths. It would be difficult to say too much in support of this whole area of fundamental research in the physics and chemistry of materials.

FIGURE 161

SPACE STRUCTURES

By Richard R. Heldenfels, Chief, Structures Research Division, NASA Langley Research Center, Hampton, Va.

Some space vehicles or structures will be launched from the earth and spend their life in space without beng requiired to make a safe landing. Landing operations will be accomplished with special reentry vehicles; the primary space vehicle must survive only the launching and space flight conditions. Conditions encountered in space are unique in comparison with our past experience and create many new structural design problems that will be discussed in this talk.

The first and most important consideration is that space vehicles must have minimum weight with maximum reliability. Weight reduction is extremely important because of the tremendous energy

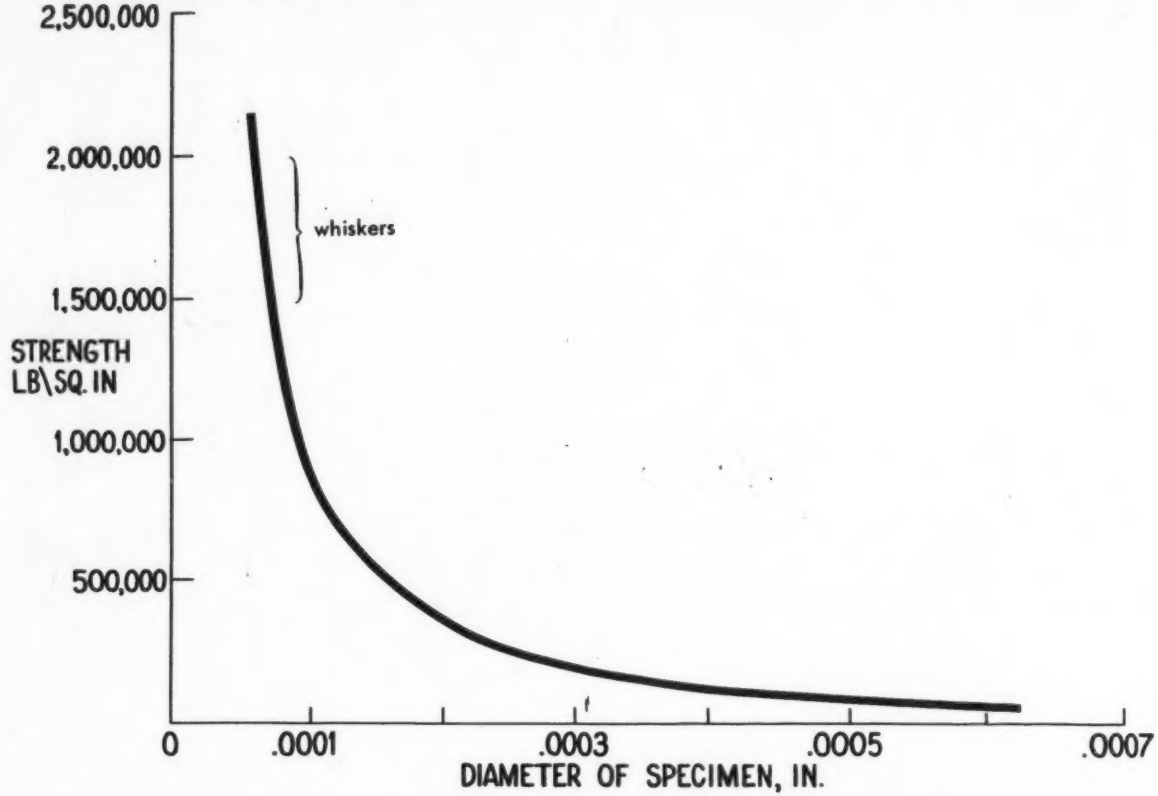


FIGURE 162. Strength of pure iron as diameter of specimen decreases.

required to accelerate each pound of weight to satellite speed. Each pound saved in the space vehicle saves many pounds of fuel, structural weight, and propulsion equipment in the launching vehicle. While weight is being minimized, the reliability of the system must be maintained at a very high level because the possibility of escape in case of a malfunction is extremely small.

To achieve minimum weight and maximum reliability, the structural design must be made to a degree of precision never before required. Better and more accurate solutions must be obtained for many familiar structural problems but more important are solutions to the new structural problems encountered with space structures, particularly novel structural configurations that have not previously been associated with aircraft or missile structures. Space structures are expected to be large and extremely flimsy by present standards. Furthermore, the problems associated with boosting these ungainly structures into orbit requires special techniques for assembling and erecting these structures in space. The ideal structure for boosting is small and compact but the ideal space structure is usually the opposite.

The space structure must also survive a very unique environment unparalleled in the past experience of man. There is no atmosphere to influence the structure. Once the vehicle is in orbit, it is in a state of weightlessness and the forces applied, even by a propulsion system during an interplanetary journey, will be exceedingly small compared with forces on present flight structures. These conditions, although advantageous in saving weight, have been rarely encountered in our experience and new design criteria must be developed to cope with them. The weightlessness problem may be particularly important because many of the structures envisoned for spaceships cannot possibly support their own weight when assembled on the ground.

Although space is seemingly empty it is infused with harmful radiations and many solid particles called meteoroids which may damage the vehicle. Thus suitable protection methods must be incorporated in the structural design.

The unique environment of space presents two problems to the structural designer. First, he must gather precise data for the characteristics of this new and hostile environment. Then, he must determine how seriously this environment affects the structures and develop methods and techniques for overcoming these detrimental effects. Development of the required structural methods cannot wait until the environment is completely defined; these two processes must proceed simultaneously.

UNMANNED ERECTABLE SATELLITES

Figure 163 shows an unmanned satellite that may be used in the near future to relay communications or make weather observations. It is called erectable because its size and shape requires that it be erected after it is in orbit. The large antenna at the bottom and equipment in the body perform the functions of the satellite. The large solar energy collector at the top furnishes heat to drive the electrical power generation system. The heat energy rejected by the power system is radiated into space from the body of the satellite.

The antenna and collector are large ungainly structures that would be very heavy if constructed like similar structures used on Earth.

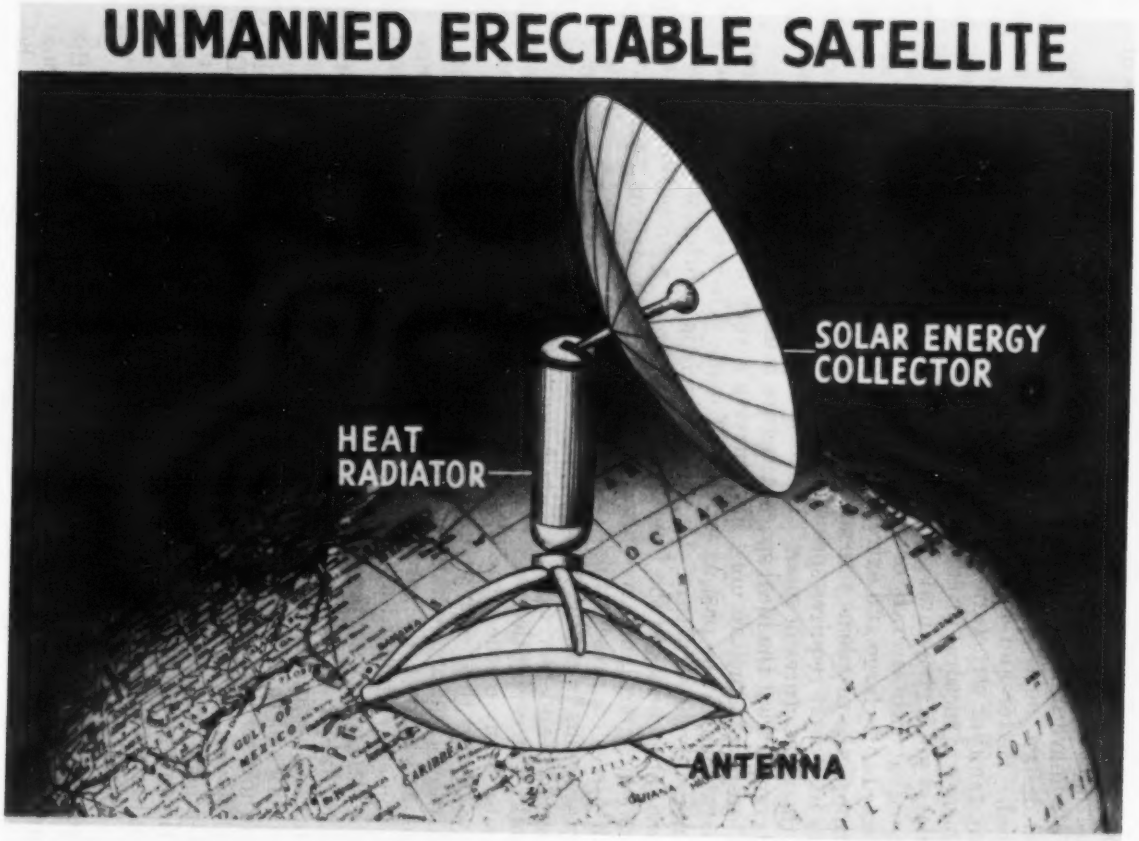

UNMANNED ERECTABLE SATELLITE
SOLAR ENERGY COLLECTOR
HEAT RADIATOR
ANTENNA
GULF OF MEXICO
CARIBBEAN

FIGURE 163

For use in space, however, they can be made of very thin material such as a metal-plastic combination that looks like a chewing-gum wrapper. The problem is to devise a structure of this material that can be folded into a small package and then automatically erected and maintained in the required shape.

MECHANICALLY ERECTED SOLAR COLLECTOR

Figure 164 shows two methods being studied for forming the solar energy collector. A mechanical system can be used to form a dish in the same way that an umbrella is erected. The full-scale satellite with its diameter of about 30 feet would be much larger than an ordinary umbrella. The collector starts out as a concentrated shape in a small tube but by proper actuation it is quickly erected into a stable shape of the desired size and configuration. A 10-foot diameter, mechanically erected, collector of the umbrella type has been constructed and is currently undergoing tests. The accuracy of the parabolic collecting surface has been determined and other erecting methods and structural arrangements for providing a more accurate shape are under study. A determination of the efficiency of this 10-foot dish as a solar energy collector is now in progress.

INFLATABLE STRUCTURES

Another approach is to use a gas to inflate the dish. In this case a coil of inflatable tubes is used for forming the structure. Many forms of inflatable structure can be made, in fact the antenna portion of the satellite may be an inflatable structure whereas the mechanical system may be used for the solar energy collector. The first inflatable structure developed for satellite experiments was a simple 30-inch diameter sphere. The sphere is launched as a small compact package (2 by 2 by 3 inches) and in space a small bottle of air (1¼ by 2 inches) can very quickly erect it.

Once the 30-inch sphere is inflated it will hold its shape quite well with no pressure on the inside. For other applications, the material itself may not have sufficient stiffness and auxiliary means such as foamed plastics must be provided to incorporate the required stiffness. Another technique being studied for erecting and maintaining the shape of space structures is the utilization of centrifugal forces obtained from spinning.

Inflatable structures have characteristics attractive for use in many space and reentry vehicle structural applications. Research is underway to define the structural characteristics of inflatables constructed of fabrics or pliant membranes. Recent NASA research has resulted in theoretical methods for predicting the structural failure of a variety of inflatable structures configurations and for calculating the deflections under static and dynamic loads of winglike inflated structures. The accuracy of these theoretical methods have been checked by strength and vibration tests of small inflated structures in the laboratory.

ONE-HUNDRED-FOOT INFLATED SPHERE

A notable achievement during the past year has been the perfection of techniques for erecting and maintaining the shape of a passive communication satellite by the inflation technique. This satellite is

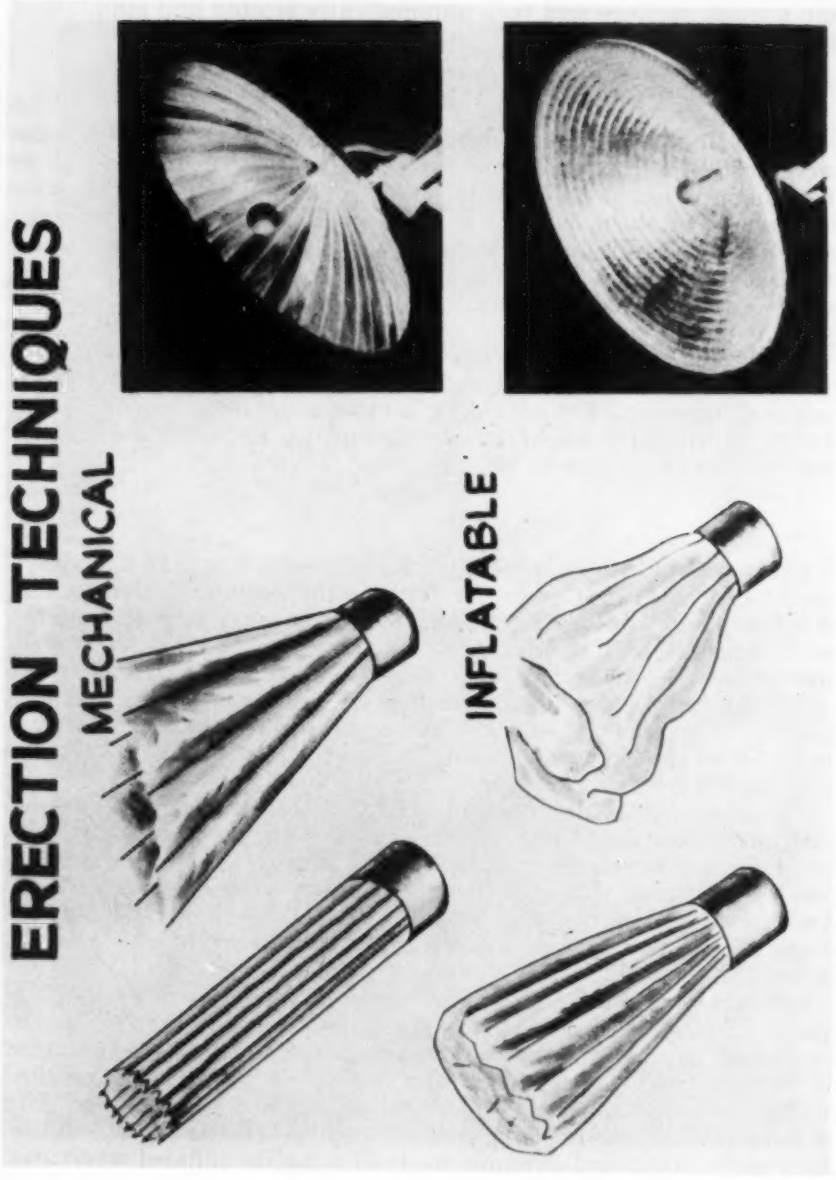


FIGURE 164

a 100-foot diameter sphere constructed of 0.0005-inch thick aluminized mylar. It is launched into space as a compact package in a 30-inch diameter container and then erected and sustained by internal pressure. Folding and packaging methods have been devised so that the erection process can be accomplished without damage to the very thin skin. Two techniques (a vaporizing fluid and a subliming solid) for pressurization have been subjected to a comparative evaluation. In each case the low vapor pressure of the material causes it to evaporate in the high vacuum of space and thus inflate the sphere. Evaporation continues slowly to restore pressure lost by leakage through micrometeroid punctures in the skin. Nonorbital, high-altitude rocket test flights (Shot Put) have been made from the NASA Wallops Station to check the behavior of the packaged sphere during the boost phase and the operation of the inflation system. Thousands of people along the east coast of the United States saw the inflated spheres; each appeared as a very bright evening star for several minutes. Some brief communications experiments also were made successfully during these tests. A subliming solid system, consisting of two powders, has been selected for use in the orbital tests planned in the next few months. The first powder, benzoic acid, sublimes quickly and provides the initial inflation before the sphere completes the first orbit. The second, antraquinone, sublimes very slowly and will provide sustaining pressure for at least 2 weeks.

FIGURE 164

MANNED SATELLITES

Figure 165 shows two types of manned satellites. On the right is the capsule presently being designed for Project Mercury and on the left is one concept of a manned orbital laboratory. Project Mercury provides the minimum equipment needed to support a man in orbit for about 1 day and then return him safely to earth. The structure of this vehicle is designed primarily by the boost phase and the reentry into the atmosphere and is thus much more like a hypersonic airplane structure than the space structures being discussed in this presentation.

The problem of providing a reliable pressure cabin for the man is much more critical for the orbital laboratory than for the capsule because the laboratory should have a useful life of many years. The cabin must be leakproof to prevent a gradual loss of its precious atmosphere, the chance of a puncture by a meteoroid must be extremely small, and, in the event of an unexpected puncture, catastrophic failure of the cabin must not occur. The orbiting laboratory is extremely large and placing it in orbit will probably require that it be assembled from pieces. One proposal is that satellite stations be built from the fuel tanks of the launching vehicles used to place them in orbit. Whatever the technique employed there are obviously many problems involved in the construction of such a large structure in space.

FIRST MANNED SPACE STATION

The structural problems of manned space stations are being attacked through studies of configurations that could be utilized for the first stations to be placed in orbit. This space station must be light in weight and compact for compatability with available launching ve-

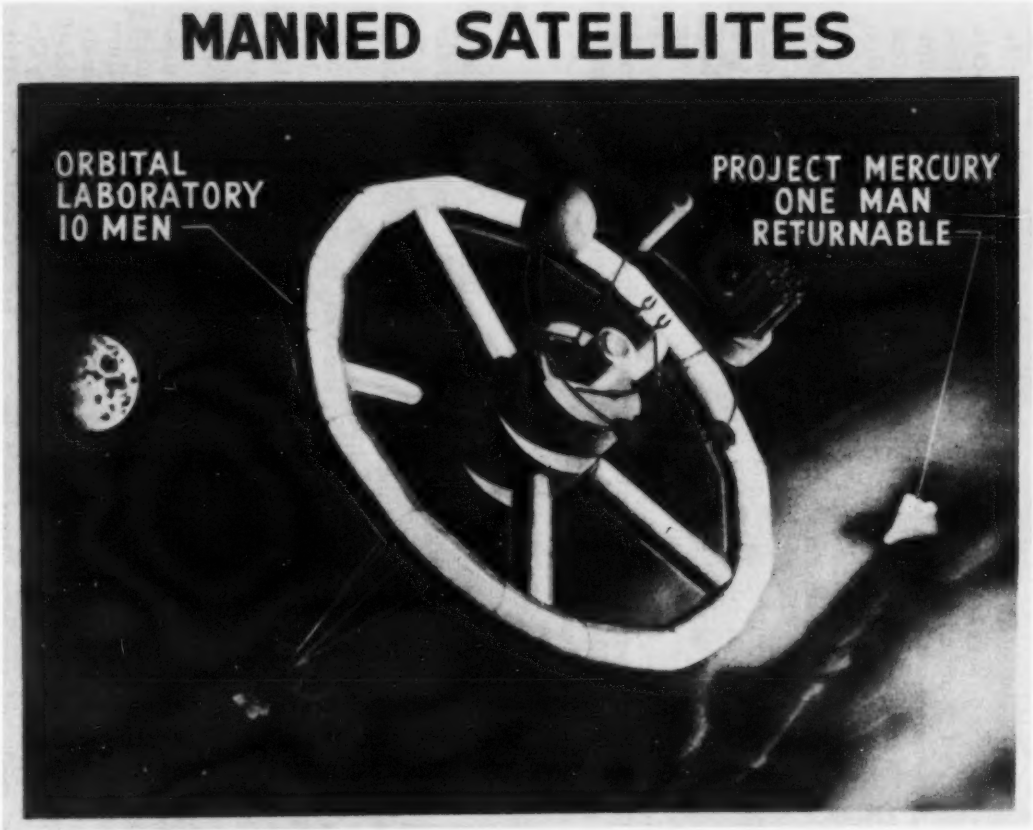

MANNED SATELLITES
ORBITAL
LABORATORY
10 MEN
PROJECT MERCURY
ONE MAN
RETURNABLE

FIGURE 165

hicles. It must be capable of automatic erection from a single package without men on board; the crew will be delivered by separate ferry vehicles which may be like the Mercury capsule or the Dynasoar vehicle. Two space station configurations have been investigated, a cylindrical station having a hard metallic shell and a toroidal station having an inflatable structure. The major portion of the toroidal station would be inflated, but much of the equipment would be contained in a central, hard metal cylinder. It would resemble the station shown in figure 164 but be much smaller. The toroidal station has numerous advantages for the first operations but its development requires research on the new materials and structural configurations used. The principal problem is to develop a reliable space cabin that can be automatically erected in space from a folded condition. Leakage of the precious atmosphere through the material cannot be permitted, the material must be free of obnoxious odors, and the cabin wall must not tear if punctured and be readily repairable when damaged by micrometeoroids. Research is underway on flexible materials suitable for the inflated toroidal cabin.

METEOROID DAMAGE

Figure 166 shows how the metallic surface of a space vehicle might look under a magnifying glass after several years of exposure in space. The surface is pitted by impacts from many particles of meteoric matter. These particles are of all sizes and travel at extremely high speeds, up to 160,000 miles per hour. The smallest particles are most numerous and the frequency of occurrence decreases as the size increases. Nevertheless pound per pound the energy of these particles far exceeds anything man has generated on Earth, an order of magnitude greater than obtainable from the shaped charges used to pierce armor.

The structural designer must find ways to prevent meteoroids from penetrating vital structures such as space cabins. A resistant structure can be provided by putting sufficient material into the walls, but this solution results in an impractical weight penalty for any large structure that must have long life. A lighter approach is to use some form of meteor shield that slows down the particle and breaks it up into numerous impotent pieces. While we know that such a principle will work, the design details have yet to be developed. Two factors are currently delaying the solution.

First is the lack of definitive information on the meteoroids themselves and the damage they can inflict. The actual sizes, densities and speeds of the meteoric particles are not accurately known and special satellite experiments must be made to obtain this detailed engineering data. Satellite data obtained to date has not resolved the wide disparity of past estimates. Consequently, a special meteoroid experiment has been designed for launching by one of the early Scout vehicles. One hundred sixty pressurized cylinders (each about the size of a beer can) will be used to obtain data on punctures caused by meteoroids. Additional detectors of other types will be included also to correlate the puncture data with other meteoroid experiments.

In the second place, we are presently unable to generate meteoroid velocities in ground test faciliites. Some progress is being made with

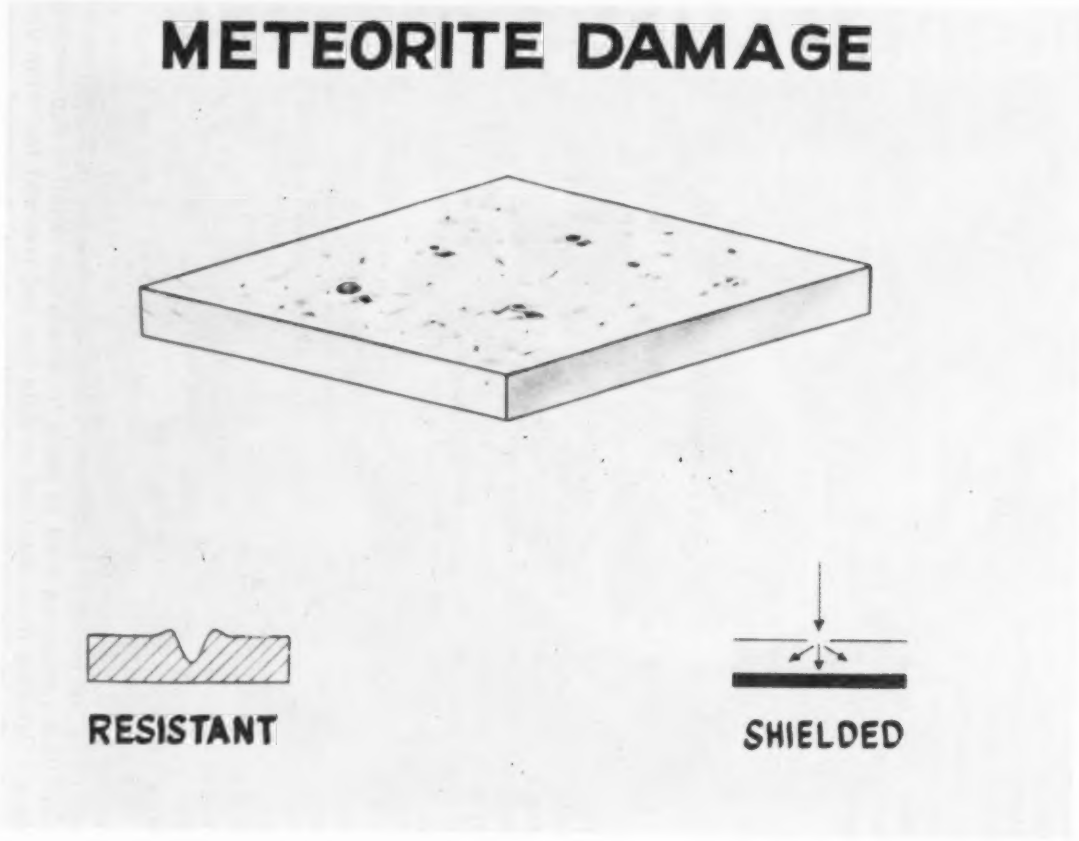


FIGURE 166

gun-launched projectiles and other techniques to get velocities up to about one-tenth the maximum meteoroid velocity. This apparatus is being used to determine the damage caused by simulated meteoroids and the effectiveness of multilayer shields. Although valuable information is obtained from such tests, higher velocities are needed. The feasibility of several techniques for producing very high speed particles are under study. One promising technique uses a high electrostatic potential to accelerate a small charged particle. The velocity obtainable with this method depends upon the electrical charge that can be placed on the particle; research is currently underway to establish the amount of charge obtainable and thus the velocity that can be achieved.

RADIATION DAMAGE

The greatest deterrent to manned exploration of space is cosmic radiation. Data defining the severity of this danger are very meager at present, but indications are that man cannot safely venture on distant journeys into space without the protection of radiation shields. Fortunately, structural materials are much less susceptible to radiation damage than are living organisms. The structural designer must, however, solve the problem of incorporating radiation shielding into the structure of space vehicles so that the optimum combination of structure and shield is used to achieve a minimum system weight.

SPACE SHIP STRUCTURES

FIGURE 166

Figure 167 shows two spaceships that might be used for an interplanetary journey. These vehicles were designed to carry a crew of eight men to Mars and return, a trip that would require about 3 years. Two vehicles are shown since both nuclear rocket and nuclear electric propulsion systems are possibilities. In each case the size and configuration of the vehicle is determined by the propulsion system. Each is very large, weighing over 150 tons, the longer one being 600 feet long. For each of these vehicles the structural designer is faced with the problem of providing a very large but light structure that can be erected and assembled in orbit. The nuclear rocket requires hydrogen propellant that must be stored in extremely cold tanks and large shields are required to protect the tanks from solar heating and meteoroid damage. The nuclear electric propulsion system is characterized by a very large radiator (about 1 acre in area) for disposing of the unusable heat from the electric generation system. Each ship illustrated is only a preliminary idea of what an interplanetary vehicle would look like, but clearly indicates that there are numerous new structural design problems to be solved before such a vehicle is possible.

LUNAR VEHICLES

Because of the futuristic nature of the spaceships discussed previously little work directly associated with the structures of such vehicles has been undertaken. Of more immediate interest is a vehicle for circumnavigation of the Moon. The major structural problem of a lunar reconnaissance vehicle is providing capability to withstand the severe heating encountered on return to the Earth's atmosphere. These structural problems are similar to but more severe than those

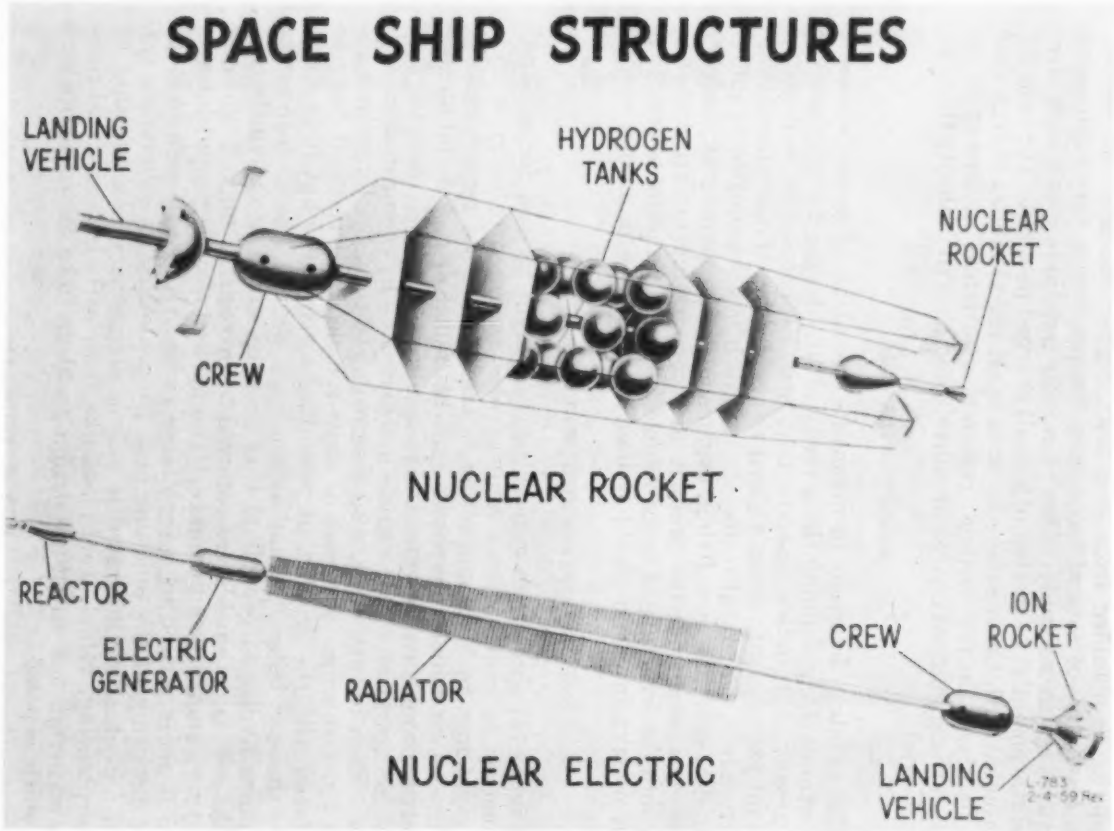

SPACE SHIP STRUCTURES
LANDING VEHICLE
HYDROGEN TANKS
NUCLEAR ROCKET
CREW
NUCLEAR ROCKET
REACTOR
ELECTRIC GENERATOR
RADIATOR
CREW
ION ROCKET
NUCLEAR ELECTRIC
LANDING VEHICLE

FIGURE 167

of hypersonic aircraft. Research on thermal protection systems continues as a major part of NASA structures research. Thermal protection systems for various types of ferry vehicles used to make trips to and from orbiting space laboratories are the subject of a continuing research effort; additional thermal protection research applicable to lunar vehicles is also underway.

To summarize the above remarks, space vehicle structures will be of novel and unprecedented configurations and must withstand a hostile and unfamiliar environment with maximum reliability. Because of the extreme importance of structural weight, design procedures must be refined to a degree of precision heretofore uneconomical. The necessity for boosting the ungainly configurations from Earth into orbit requires the development of many new methods and procedures for erecting and assembling structures in space. Research directed toward these problems is currently underway.

VERTICAL TAKEOFF AND LANDING AIRCRAFT

By John P. Campbell, Head, Dynamic Stability Branch, Aerospace Mechanics Division, NASA Langley Research Center, Hampton, Va.

A vertical takeoff and landing or VTOL aircraft is one that takes off vertically, changes from hovering to forward flight, cruises to its destination and then returns to hovering flight and performs a vertical landing.

TYPES OF VTOL AIRCRAFT UNDER STUDY

VTOL aircraft can take many different forms but it is possible to group these aircraft into five basic types according to their means of propulsion. These five types are rotor, propeller, ducted fan, turbojet, and rocket, listed in the order of their top speed capability, with rotor types at the low speed end, rocket types at the high speed end.

This statement will be concerned with propeller, ducted fan, and turbojet VTOL aircraft and with some of the rotor aircraft other than the helicopter. We exclude helicopters because they represent a well-developed VTOL type which actually constitutes an entire aircraft field in itself. NASA research in the VTOL field has been closely related to service interest in this field. In some cases basic or exploratory research by the NASA has resulted in promising new ideas for VTOL aircraft, and this information has been brought to the attention of the services and industry. Later at the request of the services we have performed the applied research required in the development of specific VTOL aircraft. A good example of this relationship between NASA and the services is in the development of the turboprop VTOL transport.

In figure 168 we have some VTOL research models that we have used for exploratory research in this field starting about 9 years ago. Two of these models on the left are called deflected slipstream configurations because they have large flaps which deflect the propeller slipstream downward to produce the vertical lift for hovering flight. Our research has indicated that these are not very promising types for vertical takeoff and landing or VTOL operation because of the

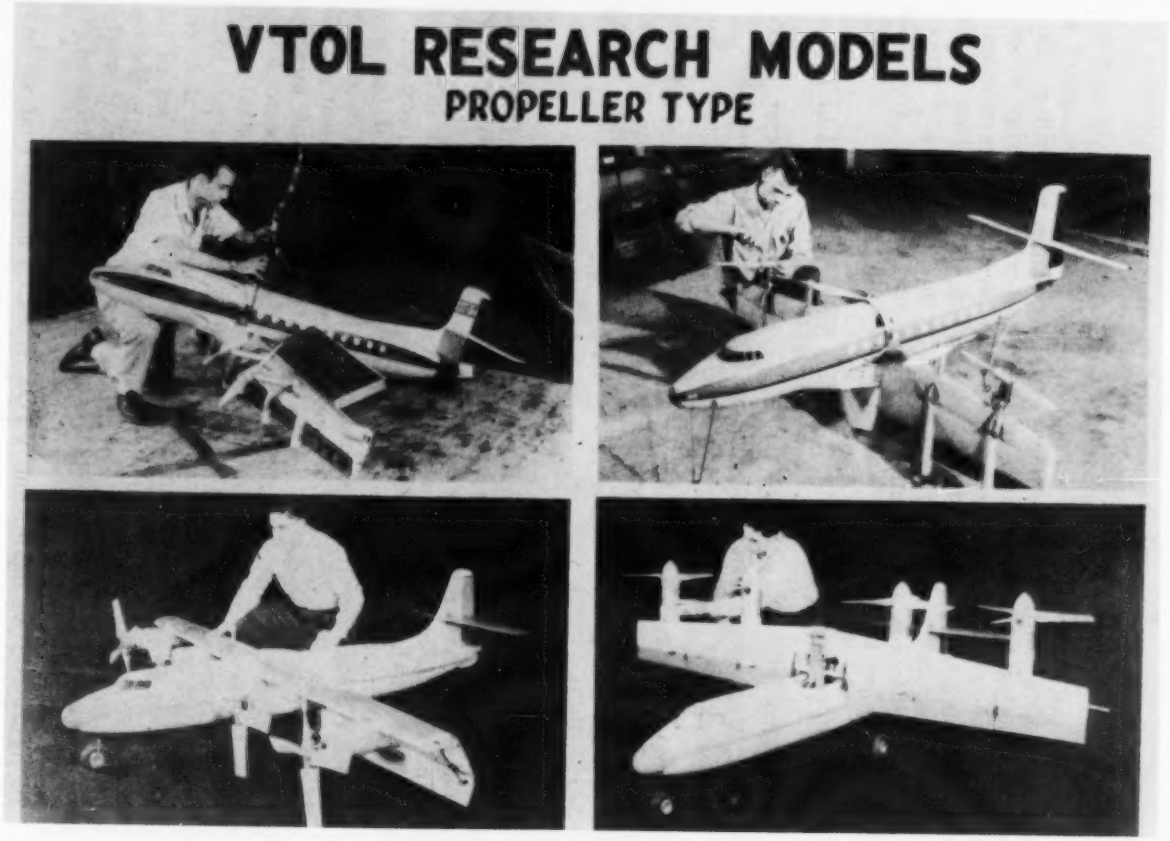


FIGURE 168

thrust loss incurred in turning this propeller slipstream downward with a flap. But they are good machines for short takeoff and landing or STOL operation.

The configuration at the upper right of figure 168 is a tilt-wing configuration; that is, the wing and the propellers are in the position shown here for vertical takeoff and landing, and for cruising flight they rotate downward to the normal position. This is a good VTOL configuration, but it is not as good for short takeoff and landing operation as these configurations with the large flaps.

The model at the lower right of figure 168 represents a combination VTOL–STOL machine with a tilt wing and with flaps which can be deflected at low speed. This configuration combines the best features of these other configurations and appears to be a very promising combination VTOL–STOL airplane type. It can perform both vertical takeoff and landing, and short takeoff and landing.

FIGURE 168

PROPELLER-DRIVEN VTOL RESEARCH AIRCRAFT

The research that we have done with these and other similar models has resulted in the construction of the VTOL research airplanes shown in figure 169. These airplanes are sponsored by the services for the purpose of obtaining preliminary information on the flying qualities of VTOL airplanes. Research machines of this type are sometimes called flying test beds because they are simple and usually crude-looking machines intended only for research use.

Since they are less expensive than operational prototypes of military airplanes, they afford the services an economical means of obtaining flight research data on VTOL aircraft. The two machines at the top in figure 169 are the Vertol tilt-wing machine and the Ryan deflected slipstream machine both sponsored jointly by the Navy and the Army. The configuration at the bottom is the Hiller X–18 tilt-wing machine sponsored by the Air Force.

We have worked closely with the services and the contractors in the design and development of these machines and at present we have the Vertol and Ryan machines for use in flight research programs.

COMMERCIAL USES OF PROPELLER-DRIVEN VTOL AIRCRAFT

All of this work with models and with airplanes is leading toward the development of what we consider is probably the most promising VTOL airplane, that is the turboprop VTOL transport.

In addition to the military interest in such airplanes, there is also an increasing commercial interest in aircraft of this type. One possible operation of such a commercial machine is illustrated in figure 170. It would operate from a heliport located on a pier near the center of a city.

This is just one possible operation. Since a VTOL airplane of this type could have a cruising speed comparable with that of conventional turboprop transports, and since it could operate from "close in" airports such as this, it could obviously make a large reduction in the time required to travel from city center to city center.

An airplane of this type will cost a lot more to build and operate than a conventional transport because it will be about 25 percent

VTOL RESEARCH AIRPLANES
PROPELLER TYPE
NAVY
ARMY
NAVY
ARMY

FIGURE 16b

FIGURE 170

heavier and it will require more than twice as much power for a given passenger capacity.

ROTOR, DUCTED FAN, AND TURBOJET VTOL RESEARCH AIRCRAFT

On the other three types of VTOL aircraft, the rotor, ducted fan, and turbojet types, NASA has done the same type of basic and applied research.

In figure 171 we have three rotor configurations. At the upper left is the McDonnell XV–1 which has a rotor for hovering flight and a pusher propeller for forward flight. It is shown here mounted in the NASA Ames 40- by 80-foot wind tunnel for force testing. The configuration at the lower left is the Bell XV–3 tilting rotor converti-plane. The rotors are in the position shown here for takeoff and landing, and for the transition to cruising flight, the rotor shafts tilt downward so that the rotors serve as propellers. The machine at the right is a flying platform machine that the pilot controls merely by leaning in the direction he desires to go.

In figure 172 we have three ducted fan configurations. A ducted fan might be considered a propeller with a ring or shroud around it. At the upper left we have the Doak tilting machine which is another service sponsored flying test bed the NASA is working on. The machine at the lower left here is an aerial jeep which the Army is very much interested in. This type of machine would have a low top speed, less than 100 miles per hour, but it should be simple and easy to fly and should be suited to flying at very low altitudes or in the "nape of the earth," as the Army people put it.

The configuration at the right in figure 172 is the Hiller flying platform which is flown in the same manner as the aerocycle shown in the last figure, that is, the pilot just leans in the direction he desires to go.

Figure 173 shows four turbojet configurations. The machine at the left here is the Ryan X–13 which has a hook on the nose to engage the cable on its landing service trailer for vertical takeoff and landing. Transition to forward flight is performed by tilting over from a vertical to a horizontal attitude.

From practical considerations the services now seem to prefer the configurations where the fuselage remains horizontal as in the Bell X–14 shown at the upper right in figure 173. The X–14 has two small jet engines in the forward part of the fuselage with some vanes at the tailpipe beneath the wing to deflect the jet exhaust downward to provide the lift for hovering flight. The model at the lower left is a model of the Bell XF–109 airplane, an interceptor type. It has two jet engines in tiltable pods at each wingtip. It also has two more jet engines in the fuselage at the nose and two more at the tail to help provide the vertical lift for hovering flight.

Shown at the bottom right in the same figure is an artist's drawing of a futuristic configuration. It represents a mach 3 turbojet transport with its main propulsion engines in tiltable pods out at the wingtips in the position shown here for hovering flight. This machine would also have a number of lightweight lifting engines mounted vertically in the fuselage and used only for takeoff and landing. When we consider the problems just involved in developing a conventional turboprop transport for mach 3 and then include these problems

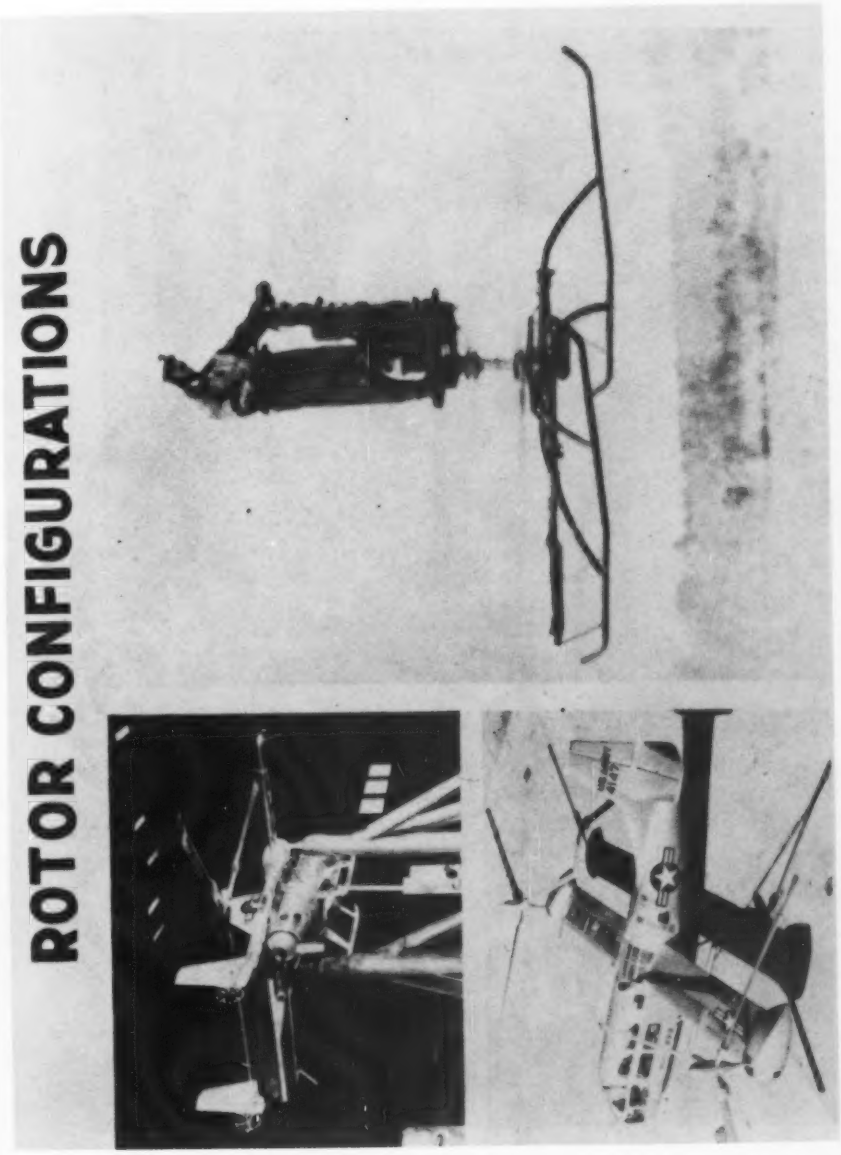


FIGURE 171

FIGURE 172

FIGURE 172

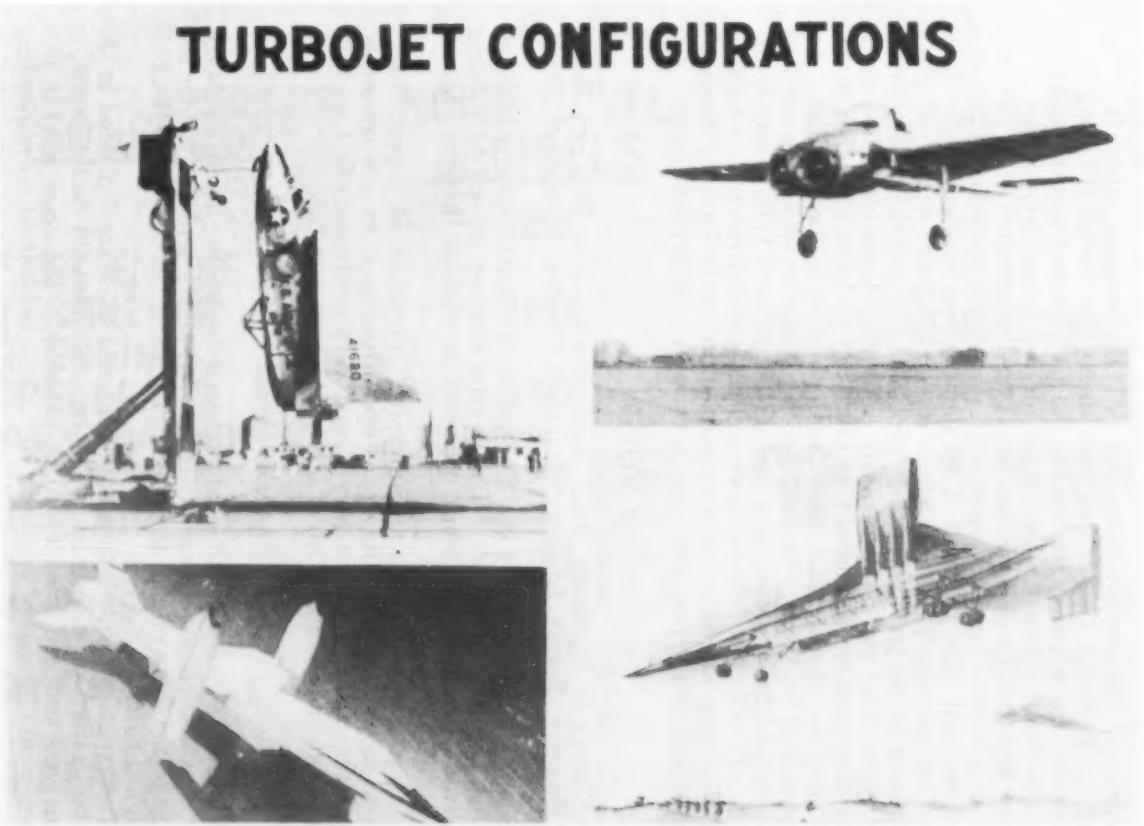


FIGURE 173

involved in developing this vertical takeoff and landing feature, it is apparent that machines of this type are still quite a ways off.

During the past year, the NASA has continued its research in the VTOL-STOL field with the emphasis on flight research employing a number of the service-sponsored VTOL research aircraft. The Langley Research Center has been using the Vertol tilt-wing configuration for research studies for the past several months and now has the Doak tilting duct machine for use in similar studies. The Ames Research Center has conducted similar research with the Bell XV–3 tilt-rotor convertiplane, with the Ryan deflected-slipstream machine, and with the Bell X–14 deflected-jet configuration. It is felt that the results of this phase of our program will be of great assistance to the services in their problem of fitting the most promising types into useful operational concepts. Valuable information regarding possible problems that are likely to be encountered in operational use of such machines is being obtained in these studies. An extension of the work with the X–14 is planned in which the airplane will be modified to serve as a variable-stability VTOL research aircraft. It will then be used to extend the general research studies of VTOL flying qualities that were carried out at the Langley Research Center during the past year with a variable-stability helicopter.

NOISE

By Harvey H. Hubbard, Head, Acoustics Branch, Dynamic Loads Division, NASA Langley Research Center, Hampton, Va.

Sound that we perceive is a fluctuation of the atmospheric pressure in the vicinity of our ears. This is true whether we are considering desirable sounds such as music or speech or whether they are undesirable as in the case of noise.

Unfortunately noise is an unwanted byproduct of a great many important aeronautics and space operations and we are concerned about this noise because it may have a very profound effect on both the design and the operation of aircraft and spacecraft.

NOISE LEVELS

Figure 174 shows the effect of various noise levels. Noise levels are, for convenience, expressed in terms of decibels, and the louder the noise or the more intense the noise, the greater the number of decibels assigned to it.

The range of decibels that are of interest to us are indicated in the center column on the figure. The interval here, 20 decibels each, is equivalent to a factor of 10 in the pressure. The noise level in this room would probably be about 70. The noise level corresponding to pain in the human ear would be about 120. We are interested in even higher pressures than this. A value of 180 would represent pressures a thousand times as high as those that would cause pain in the human ear.

There are also indicated on the chart some sources and environments of noise, some of which are very serious. The ones that are on top of this list, the ones that generate the highest noise levels, are the sources that are of particular concern to us in our work.

SIGNIFICANCE OF NOISE LEVELS

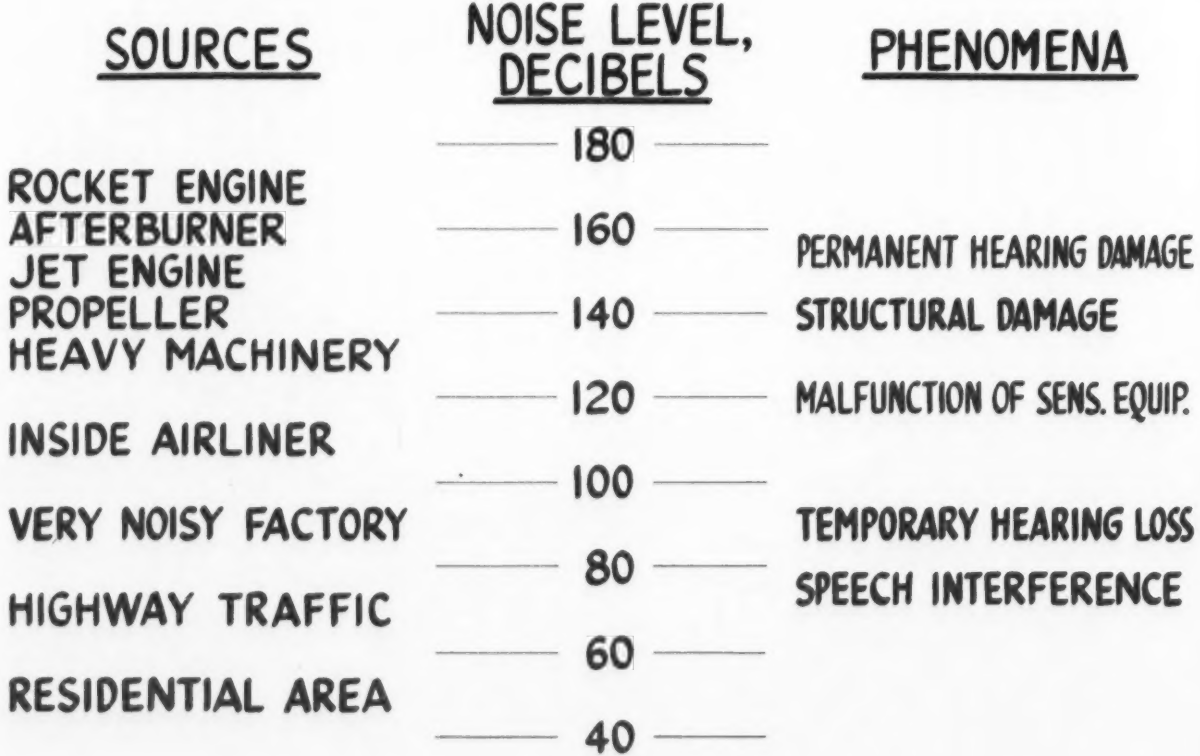


FIGURE 174

Shown also are the phenomena or results of noise exposure, and these include such things as speech interference, temporary hearing loss, malfunction of equipment, structure damage, and permanent hearing damage.

JET ENGINE NOISE

The jet engine is a source of quite a lot of our noise troubles and probably the best publicized problem is the airport problem. Jet transport operations are restricted in some of the large population centers. One obvious solution to this problem would be to have an airplane that we could fly in a steep climb to a satisfactory altitude in as short a ground distance as possible. This solution has been used in the case of propeller-driven airplanes quite satisfactorily, but the jet transport airplanes at present are not designed in such a way that they can be operated in this manner.

So we have to look to other means of solution to this problem. Two solutions are suggested from figure 175. We know from our research that some noise is generated inside the engine. We also know that the main source of noise is outside the engine, and it comes from the region where the hot high-velocity gas mixes with the cool surrounding air. This results in a highly turbulent mixing region from which most of the noise comes. We know from our laboratory tests that the noise is very much a function of the velocity of the jet. The higher the velocity, the more noise. This suggests that we ought to operate our engines at a lower jet velocity. This can be done up to a point but a lower velocity engine is a larger and a heavier engine, so we would have to pay a penalty in terms of weight.

Another approach to this would be to attach some gadgets at the end of the engine to operate in some way on this mixing region to reduce the noise, and this is another approach that is being actively pursued.

Some companies are offering engines now that do operate at a lower jet velocity. Furthermore, mixing devices are installed on the engines of current jet aircraft and these devices do offer some more reduction.

Figure 176 shows what these gadgets look like. These, of course, are research models, but they do resemble quite closely some of those that are flying today. These give a modest noise reduction and they have a modest performance penalty attached to them. If we were to expect considerably larger noise reductions with these types of gadgets we would have to expect to pay large performance penalties. These operate on the principle of exposing as much surface area as possible of this high-velocity jet to the surrounding air so that it mixes rapidly.

Our research has shown one other version of these that seems to have some promise. This is mainly the use of an additional shroud which fits on the end of a nozzle. It hastens the mixing even more and gives substantially more noise reduction. This shroud can be retracted and it thus has an acceptable penalty.

STRUCTURAL DAMAGE

Another problem that we have with jet engines is that of noise-induced structural damage. This is most serious on multiengine airplanes, and the damage occurs in regions such as is shown in figure 177

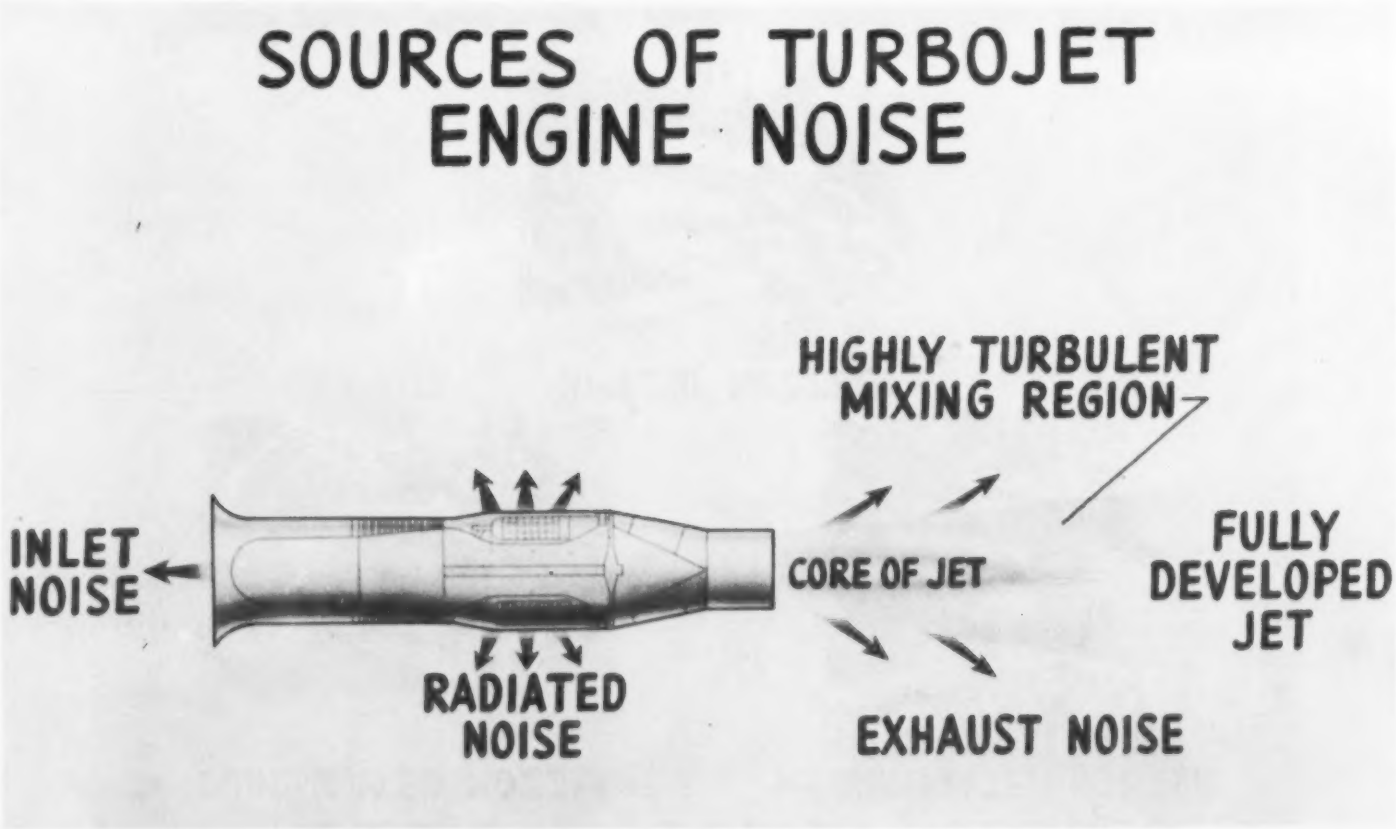

SOURCES OF TURBOJET ENGINE NOISE
HIGHLY TURBULENT MIXING REGION
INLET NOISE
CORE OF JET
FULLY DEVELOPED JET
RADIATED NOISE
EXHAUST NOISE

FIGURE 175

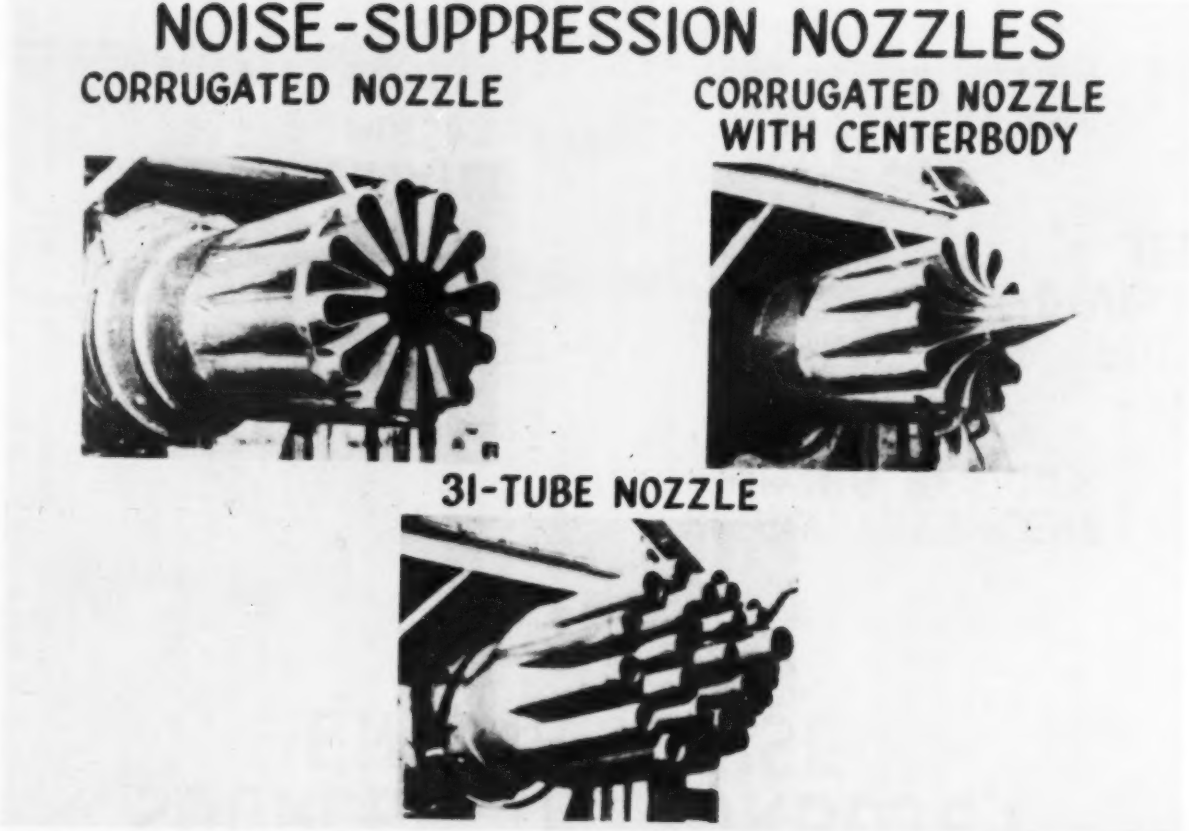

NOISE-SUPPRESSION NOZZLES
CORRUGATED NOZZLE
CORRUGATED NOZZLE WITH CENTERBODY
31-TUBE NOZZLE

FIGURE 176

FIGURE 176

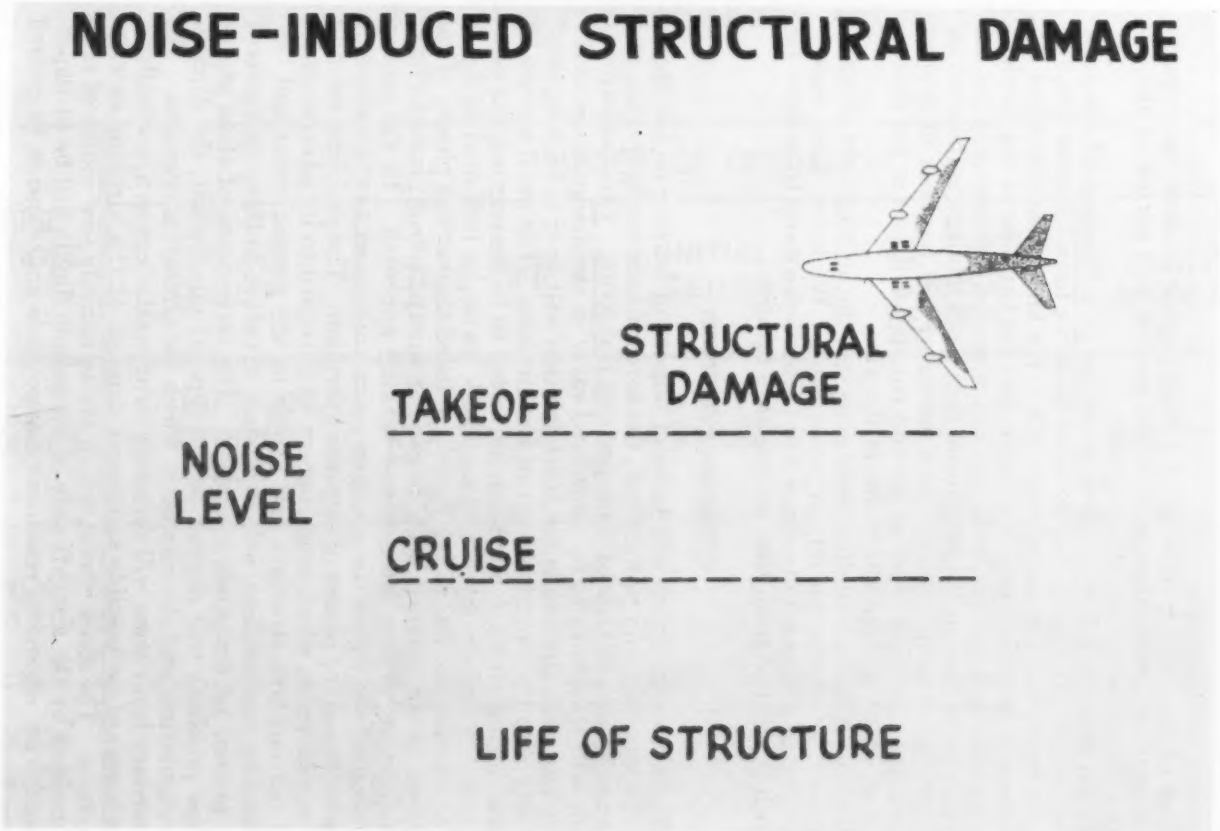


FIGURE 177

in the shading in the sketch. This is a very serious problem with all multiengine airplanes such as bombers, jet transports, aerial jet tankers. The kind of damage that we encounter is damage of the secondary structure of the airplane.

One of the earlier versions of a multiengine bomber was capable of essentially destroying itself on the ground in a period of about 5 hours due to noise from the engines.

If we plot the life of a given structure as a function of the noise level, we find that at the higher noise levels we have a shorter life, and at the lower noise levels a longer life. We know also that when the airplane is operating on the ground, that the surfaces of the airplane are exposed to higher noise levels than when the airplane is in the air. So this leads then to the conclusion that more damage is incurred on the ground than in the air. As a matter of fact, an hour of ground operations such as takeoff or ground runup conditions is the equivalent of about a thousand hours in the air.

Tens of millions of dollars have gone into the development of structures to withstand the intense noise loads. We know from experience that if a structure is exposed to higher noise levels than those for which it was designed, that we can have failures.

SUPERSONIC TRANSPORT

Noise considerations will have an important bearing on the choice of the structure and powerplant, the aerodynamic configuration, and the operating practices of the supersonic transport. These noise problems will thus have to be considered early in the design stage of the airplane since the means for their solution will need to be integrated closely into the overall design of the airplane. The main sources of noise during airplane operation are noted to be the engines, the aerodynamic boundary layer, and the shock waves, as indicated in figure 178. Across the top of the figure are listed the various phases of operation of the aircraft such as ground runup, takeoff, initial climb, acceleration, cruise, descent, and landing approach. In the central portion of the figure the problem areas are related to the sources of the noise and the phases of airplane operation. The problems relating to engine noise, which is of concern with regard to its adverse effects on the airplane structure and people in the ground crews and surrounding communities, will be similar in nature to those encountered in present jet transport operation. The seriousness of these engine noise problems will depend on the type of powerplant, the aircraft configuration, and the manner in which the aircraft is operated. The boundary layer noise will definitely be of greater concern, particularly with regard to possible structural damage of the airplane exterior surfaces. The shock waves, which are an entirely new source of noise generated by the aircraft only in supersonic flight, will be of importance with regard to community annoyance and damage to ground structures.

Boundary layer noise.—For supersonic transports, the boundary layer noise pressures will be higher than for subsonic transports and will be of concern not only from the standpoint of passenger comfort, but also because of possible noise-induced damage to the skin structure of the airplane. The boundary layer noise problem as it relates to supersonic transports can be discussed with the aid of figure 179.

SUPERSONIC TRANSPORT NOISE PROBLEMS

NOISE SOURCES	PHASES OF OPERATION				
	GROUND RUNUP	TAKE-OFF	INITIAL CLIMB	ACCELERATION CRUISE, DESCENT	LANDING APPROACH
ENGINES	STRUCTURE GROUND CREW	STRUCTURE	COMMUNITY		COMMUNITY
BOUNDARY LAYER				STRUCTURE PASSENGER FLIGHT CREW	
SHOCK WAVES				COMMUNITY	

FIGURE 178

BOUNDARY LAYER NOISE
STRUCTURAL DAMAGE
PROPOSED SUPERSONIC TRANSPORT
CURRENT JET TRANSPORT
EXTERNAL SURFACE PRESSURES
DISTANCE FROM NOSE

FIGURE 179

A laminar boundary layer is present at the front of the aircraft, as indicated by the unshaded part of the sketch. The transition to turbulent boundary layer occurs at a short distance back along the fuselage where the shading starts, and this turbulent boundary layer thickens up toward the rear of the aircraft as indicated by the darker shading. In both the subsonic and supersonic mach number ranges the boundary layer noise frequencies are noted to decrease as the boundary layer thickens, and hence there is a substantial change in the spectrum from front to rear along the aircraft. The figure at the bottom deals with the magnitudes of the external surface pressures. The double cross-hatched region represents the range of surface pressures estimated for a supersonic transport. These surface pressures are of low intensity in the laminar boundary-layer region, increase suddenly in the region of transition, and then vary only a small amount in the turbulent boundary-layer region, with the exception of some pressure build ups in regions of separated flow as may exist near the rear of the fuselage. Shown by the single cross-hatched region on the figure for comparison is the estimated range of surface pressures for a subsonic transport. The shaded area on the chart corresponds to surface pressures for which structural damage may occur.

The resulting surface pressures for the supersonic transport are significant because they are seen to be in the range where noise-induced structural damage may occur. Thus, in addition to an intensification of the familiar problem of providing optimum sound insulation for the passengers, there is also concern for the design of a skin structure to resist noise-induced damage over the whole area of the aircraft indicated by the shading in the sketch. Possible structural damage due to boundary layer noise imposes a much more severe requirement in design than for current jet transport aircraft.

FIGURE 179

Shock wave noise.—Additional sources of noise in the operation of a supersonic transport, which are not a problem with subsonic transports, are the shock waves generated during the supersonic part of the flight which includes the acceleration, cruise, and descent. Although the resulting sonic-boom disturbances may be observed throughout these phases of the flight, the most serious problems are associated with the acceleration since this may be accomplished at a reduced flight altitude. If proper precautions are not taken, shock wave noise pressures may be of sufficient intensity to damage parts of ground building structures such as windows in addition to causing annoyance. Figure 180 suggests two approaches to solving the acceleration problem; one consisting of a level flight acceleration and the other an acceleration in steep climb.

Airplane flight mach number is plotted on the horizontal scale and airplane altitude on the vertical scale. The cross-hatched area represents combinations of mach number and altitude which may result in damage to structures on the ground. The shaded area toward the top represents combinations of mach number and altitude for which sonic booms will be observed on the ground and which may be annoying but will not cause damage. The main objective in the flight operation is to travel from ground level to cruise conditions without intersecting the damage area. NASA flight studies have shown that increasing altitude is a very powerful factor in reducing the sonic-

53795 O—60—pt. 2——21

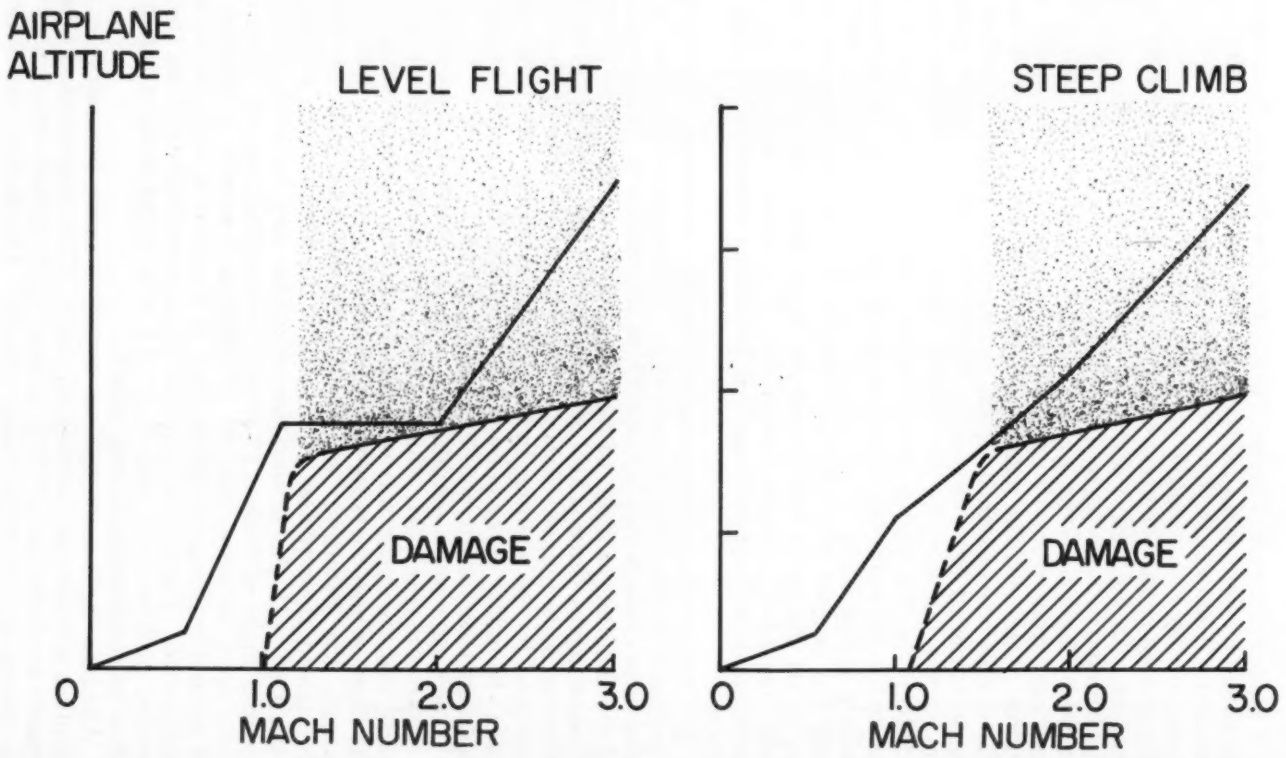

CLIMB SCHEDULES TO AVOID SONIC BOOM DAMAGE
AIRPLANE ALTITUDE
LEVEL FLIGHT
STEEP CLIMB
DAMAGE
DAMAGE
0
1.0
2.0
3.0
MACH NUMBER
0
1.0
2.0
3.0
MACH NUMBER

FIGURE 180

boom intensity. This leads to the proposed procedure illustrated on the left hand side of the figure. This consists of a subsonic climb to a relatively high intermediate altitude, a level-flight acceleration to about mach number 2, and then a subsequent climb and acceleration to cruise condition.

Another possible procedure to avoid damage on the ground during the acceleration phase of the flight is illustrated in the right-hand side of figure 180. Flight tests have indicated that if a sufficient thrust-to-weight ratio is available, a steep climb may be used to advantage to reduce the sonic-boom disturbances at ground level. The benefits are derived principally from the fact that the whole shock wave pattern is rotated by about the same amount as the airplane attitude is changed. The net result of this change in attitude of the shock wave pattern is to allow a higher mach number to be reached before the shock waves reach the ground. As a result, the damage area is now shifted to the right, that is, to higher mach numbers. As an example, this shift may be in the neighborhood of 0.2 to 0.4 mach number, depending on altitude, for a climb angle of 20°. It can be seen from the figure that acceleration to supersonic speeds can now be accomplished at a lower altitude without intersecting the damage region providing, of course, that the aircraft remains in a climb attitude.

The results of recent NASA studies have suggested that the low mach number part of the damage-area boundary as represented by the dashed line is unstable and is sensitive to atmospheric wind and temperature gradients. The high mach number part of the boundary, that is the solid portion, was noted to be relatively stable and is not very sensitive to changes in the atmospheric conditions. These results suggest that the most reliable flight procedure to avoid the damage area is the one shown on the left-hand side of the figure since the nearest approach to the damage region occurs where its boundary is most stable. On the other hand, the steep-climb procedure involves a close approach to the damage area in the region where its boundary is unstable. The implications here are that atmospheric conditions such as strong tailwinds and/or temperature inversions might tend to neutralize any benefits attained as a result of the steep-climb procedure. Atmospheric variations would present no problem in the level-flight acceleration procedure.

FIGURE 180

For a given size airplane, it is believed that only small benefits would be gained from changing its shape to reduce the boom intensities. Thus, the practical solution to the sonic-boom problem lies in the manner of operation of the aircraft. With regard to aircraft operation, two additional statements can be made. Deceleration from cruise speed should be made at as high an altitude as possible, and steep descent angles at supersonic speeds should be avoided. Any radical departures from steady or level flight conditions during any of the supersonic portions of the flight should also be avoided since these may lead to intense sonic booms over localized areas on the ground.

SPACE VEHICLES

As an example of the inside noise environment of a space vehicle during the various phases of its flight history, the interior capsule noise for the Big Joe vehicle, a full-size test capsule of the Mercury

program, is shown in figure 181. Some of the significant events such as launch, maximum dynamic pressure, booster engine burnout, sustainer engine burnout, and so forth are indicated. It can be noted that the highest noise levels were recorded during the exit phase while the vehicle was operating at its maximum dynamic pressure and were due to the aerodynamic boundary layer. This noise is of concern because it persists for an appreciable length of time and may cause difficulties in communications. There is also a concern with regard to possible acoustic-induced fatigue damage of the heat shields on the external surface of the vehicle. This latter problem is complicated by the fact that the combined effects of intense noise and high temperature environments on structural fatigue are not well understood.

The rocket engine noise, which is the main component during static firing and launch, will tend to become relatively more intense in the areas where personnel and equipment will be located as booster engines become larger and/or are clustered together, as proposed for some future vehicles.

FUTURE TRENDS

The question arises as we look to the future whether the noise problems of the future will be more or less severe than the ones that face us today, and an answer at least is suggested by figure 182. There is here plotted the maximum noise levels encountered for various well-known powerplants as a function of calendar years. The slope of these curves is generally upward, that is, more noise is generated as time goes by. This results from the fact that we are constantly striving for more powerful propulsion systems.

As a case in point, the NASA is having developed a million and a half pound thrust rocket engine which will be available in the future. It is estimated that this will generate about 70,000 horsepower of noise power. This compares to 1 to 200 horsepower of noise power from our current jet engines.

We know from experience that as more noise is generated, we have to put more effort into the noise control procedures. There is also the possibility that if noise gains are made, that they will be used up by increases in performance. So we can only conclude as we look to the future that our noise problems are continuing problems and that they will continue to require a large amount of effort for satisfactory solutions.

SUPERSONIC AIRCRAFT

By Herbert A. Wilson, Chief, Unitary Plan Wind Tunnel Division, NASA Langley Research Center, Hampton, Va.

FLIGHT EFFICIENCY

The limiting factor in supersonic cruise aircraft is the low flight efficiency that goes along with supersonic speeds. A lot of things affect the flight efficiency, such as the energy per pound of fuel, the structural efficiency of the airplane, the propulsion efficiency and the aerodynamic efficiency.

Figure 183 shows you the way the flight efficiency varies with speed.

First, the subsonic jet transports that are now flying are flying at about the peak of the curve. The figure also shows that if you get

SPACE VEHICLE INTERNAL NOISE

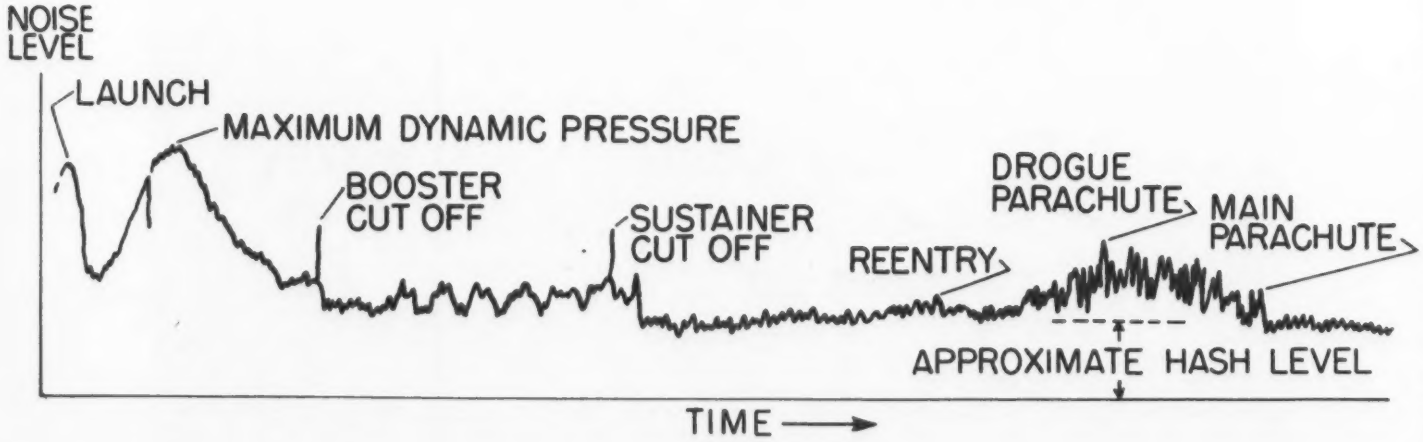


FIGURE 181

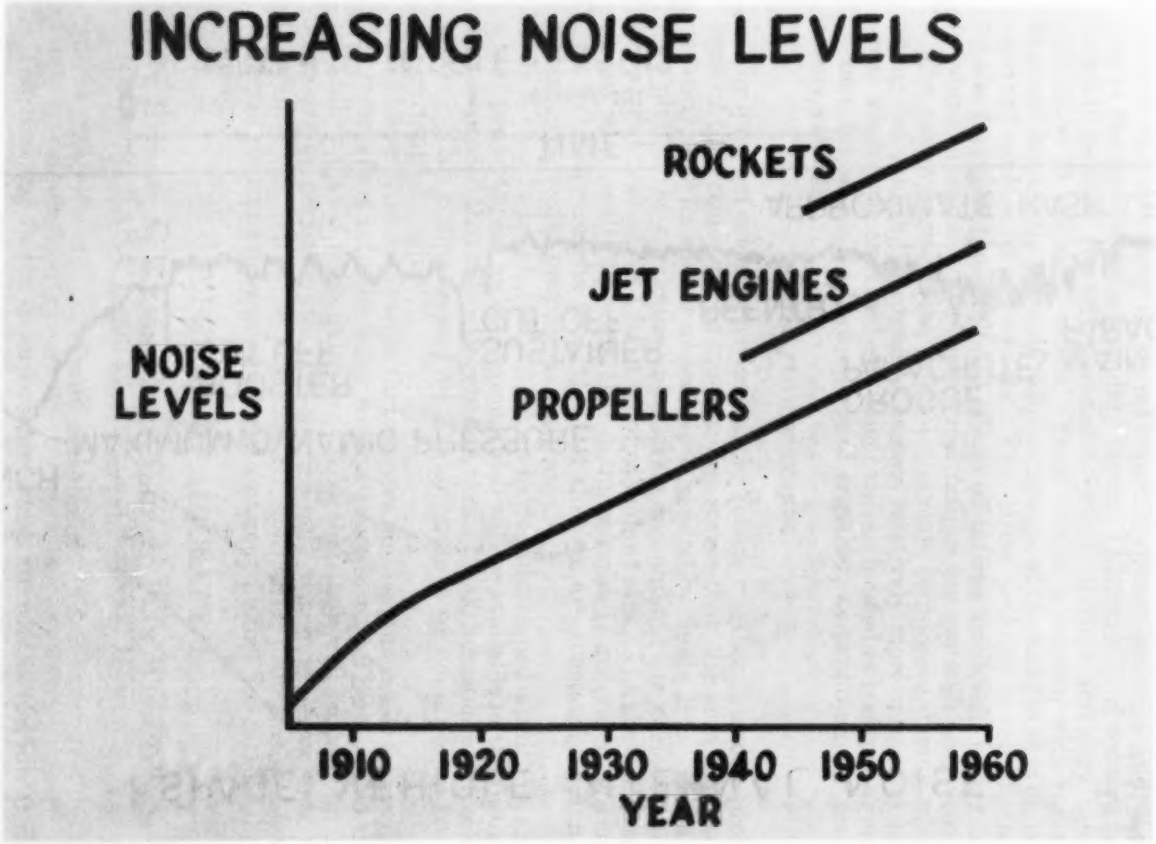

INCREASING NOISE LEVELS
ROCKETS
JET ENGINES
PROPELLERS
NOISE LEVELS
1910
1920
1930
1940
1950
1960
YEAR

FIGURE 182

FLIGHT EFFICIENCY

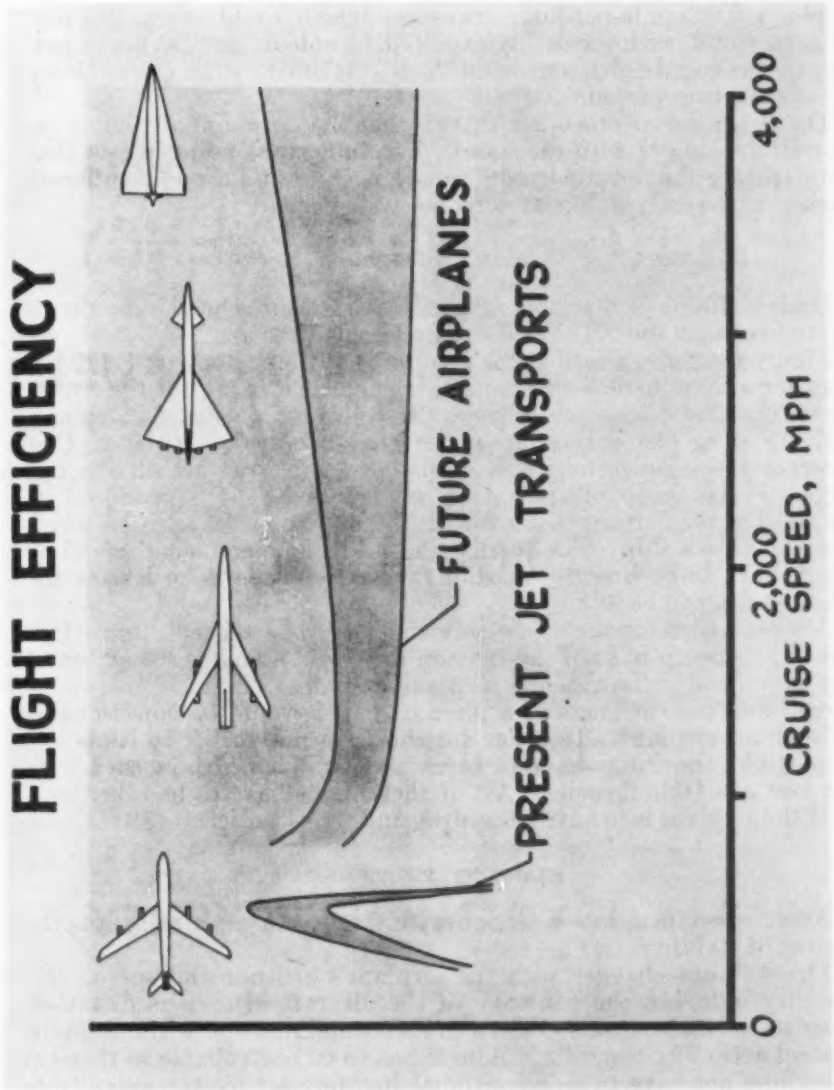

FLIGHT EFFICIENCY
FUTURE AIRPLANES
PRESENT JET TRANSPORTS
0
2,000
4,000
CRUISE SPEED, MPH

FIGURE 183

out around 2,000 miles per hour and get up at the top of the band of uncertainty, the supersonic airplanes have some prospect of competing in efficiency with the subsonic airplanes now flying. They not only have the advantages of efficiency, but they have some of the other obvious advantages which go along with high-speed flight. For example, a 2,000-mile-per-hour transport which could carry 100 passengers would, with the utility expected, be able to carry as many passengers back and forth across the North Atlantic as the *Queen Mary* in the same time period.

The figure shows one other thing—that the optimum airplane configuration changes with the speed. The important point here is that the airplane, to fly at supersonic speeds, is going to look a lot different from our currently flying subsonic jet transports.

DRAG PROBLEMS

Drag is the force that holds the airplane back and which the thrust has to overcome for the airplane to fly through the air.

Figure 184 shows the drag for a subsonic airplane compared with the drag for a hypothetical supersonic airplane. The drag for the supersonic airplane is almost three times the drag for the subsonic airplane.

Every drag element is larger for the supersonic airplane. One deserves special mention; that is the pressure drag which is quite large. It has no counterpart at subsonic speeds. It is produced by the shock wave pattern that hangs onto the airplane much like waves hanging onto a ship. The fuselage has to be long and slender and its wings have to be literally as thin as a razor blade in order for the pressure drag to be low.

Also, in order for the supersonic airplane to be efficient, its surface has to be smooth to keep the friction drag low. This is the action of the air on the surface of the airplane as it flies along. Protrusions three times the thickness of a piece of paper would be objectionable on such an airplane. In order for the drag due to lift to be as low as possible, the wings have to be curved and shaped in accord with our best available theories. All of these items have to be taken care of if the airplane is to have a low drag and thus be efficient.

STABILITY PROBLEMS

Another problem in connection with the supersonic airplanes is the matter of stability. (Fig. 185.)

The stability changes with the airplane's attitude and speed. By stability is meant the tendency of the aircraft after it is disturbed from its normal course to return to its normal position without undue control action by the pilot. Also it has to be controllable so that the pilot does not have to do a continual juggling act to stay away from catastrophic flight attitudes.

The wing and tail is just a representation, and there is indicated a pressure field, and the angles and pressure changes in the flow field. As the tail moves it can experience very abrupt flow changes which will affect the airplane. Stability changes with altitude and speed and, as a consequence, the location of the tail is critical. You cannot fix this by making the tail big, because if you do you have such a big tail on the aircraft that it penalizes the aircraft performance. One of

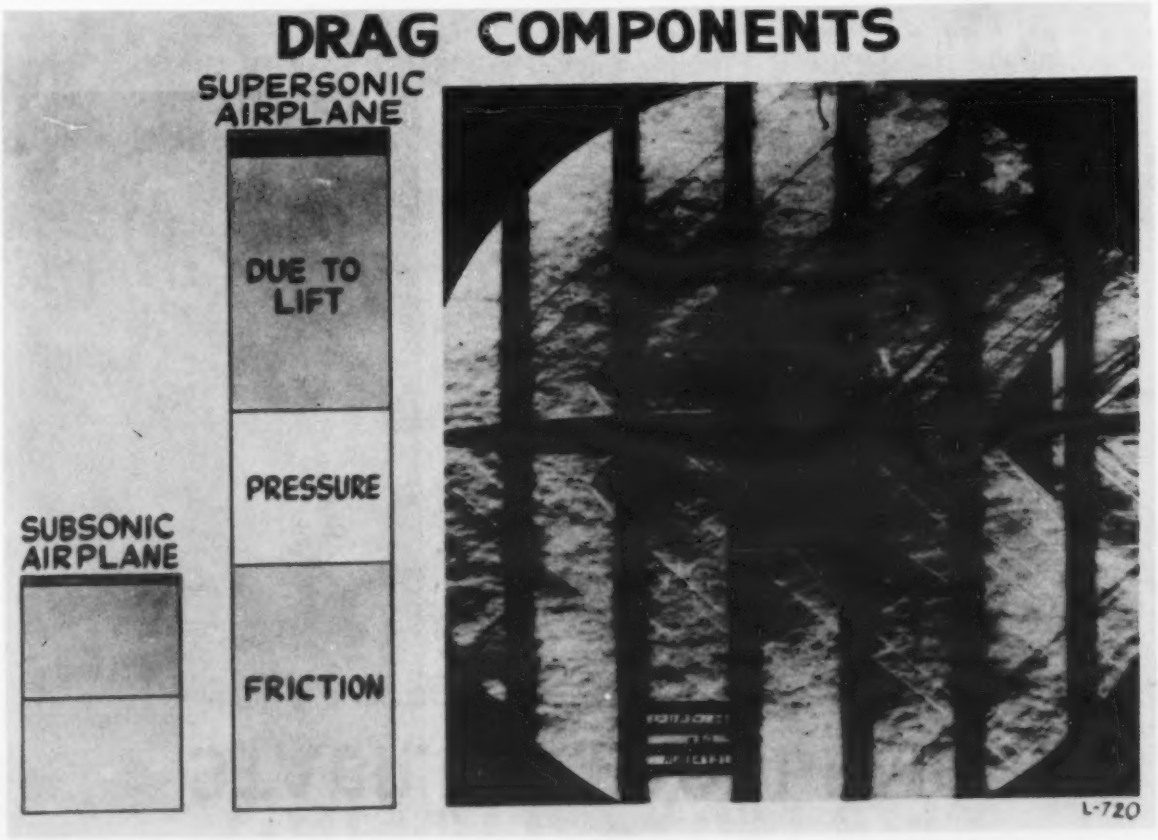

DRAG COMPONENTS
SUPERSONIC AIRPLANE
DUE TO LIFT
PRESSURE
FRICTION
SUBSONIC AIRPLANE
L-720

FIGURE 184

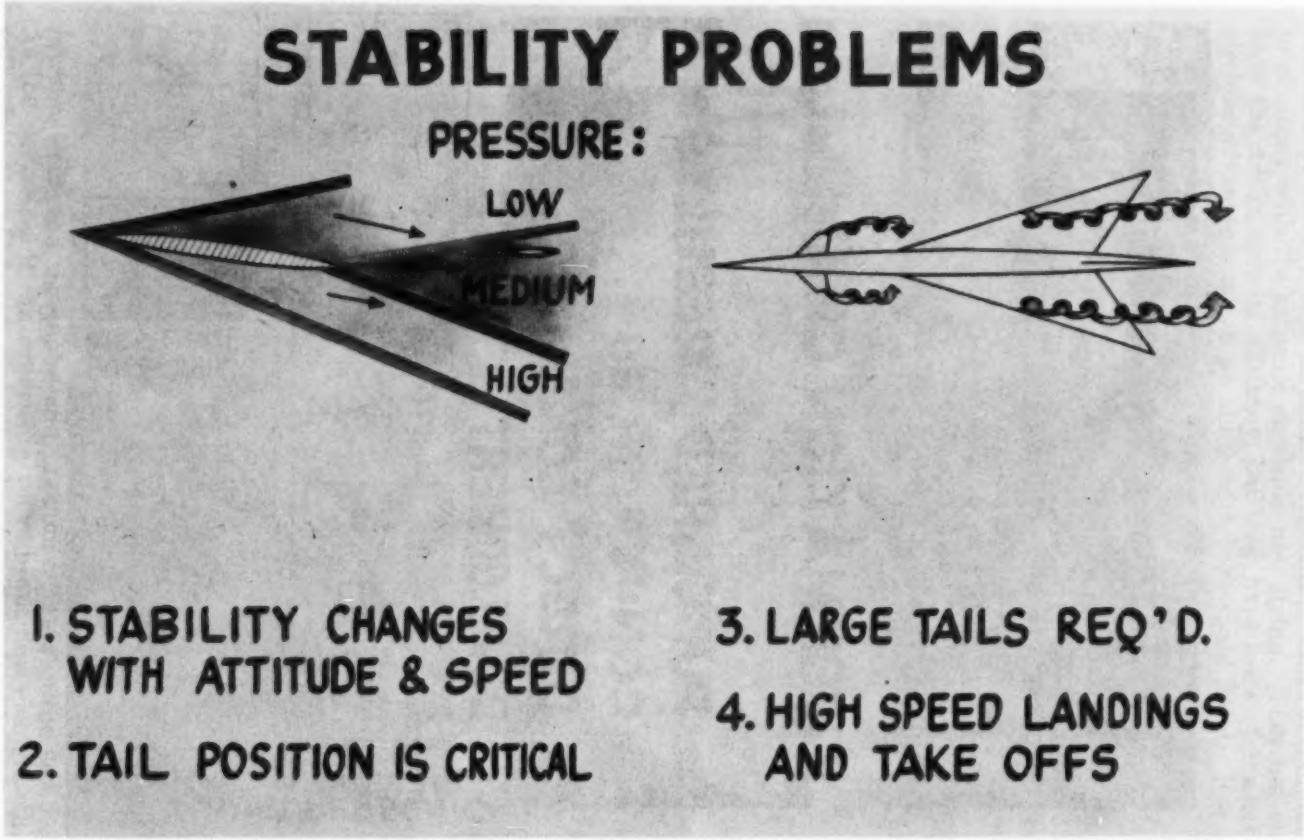

STABILITY PROBLEMS
PRESSURE:
LOW
MEDIUM
HIGH
1. STABILITY CHANGES WITH ATTITUDE & SPEED
2. TAIL POSITION IS CRITICAL
3. LARGE TAILS REQ'D.
4. HIGH SPEED LANDINGS AND TAKE OFFS

FIGURE 185

the things we do to get away from this tail problem is to put the tail out in front of the airplane, and this introduces also its own particular set of problems.

It is well established that the supersonic cruise portion of the flight plan can be executed at levels of efficiency comparable to those of present-day jet transports. The vehicles studied to date are, however, essentially supersonic configurations developed for military bombardment. Studies of the adaptation of these types to typical transport missions lead to the conclusion that they have serious limitations in "off-design" areas, specifically: take-off, climbout, inflight emergencies, and holding. The noise problem of the supersonic boom requires subsonic operation until high altitudes are obtained. The terminal or "hold" operation must be conducted at subsonic speeds and is very sensitive to hold altitudes, one-engine-out emergency during cruise may require the availability of a midrange alternate.

The technical position in terms of state of the art might be briefly summarized by saying that if the mission involved only flight at design supersonic speed and altitudes, and no emergencies occurred, intercontinental ranges of commercial interest and importance could be readily achieved. The ladders by which the airplane climbs to its supersonic cruise speed and altitude and descends therefrom, however, have broken or weak rungs. The research state of the art as of today indicates that the proper ladders for the off-design situation can be provided through some form of airplane variable geometry—such as variable sweep—in combination with an advanced fan-type propulsion system. The present research position is that no fundamental problem appears with regard to these off-design conditions that cannot be solved by concentrated research effort.

SUPERSONIC NEW YORK-TO-PARIS FLIGHT PLAN

The investigation of the operational problems of supersonic transports has covered several typical flight plans. An example of these is shown in figure 186 for a New York-to-Paris trip. Here is shown the airplane altitude versus distance from the takeoff airport (New York) with important phases of flight denoted. Starting from a standstill at the end of the runway, the airplane accelerates to takeoff speed, takes off, accelerates to climb speed and climbs subsonically to an altitude where it is permissible to accelerate to supersonic speed. From efficiency considerations, it is desirable to do this at about 25,000 feet but sonic boom noise will probably require that it be done at 35,000 feet minimum. The airplane then climbs and accelerates supersonically to a cruise altitude in the neighborhood of 70,000 feet. The supersonic cruise in this case at mach 3 or 2,000 miles per hour is carried out at the optimum altitude which increases slightly as the trip progresses because the airplane weight decreases due to the use of fuel. The terminal part of the flight begins with deceleration and descent at minimum power to subsonic speed followed by a letdown at minimum power and a hold of as much as 30 minutes, if required, and ends with an approach and landing to the destination airport, in this case, Paris. The total time required for the flight is approximately 2½ hours. Such a flight plan is to a certain extent idealized inasmuch as it does not account for such departures from optimum flight paths

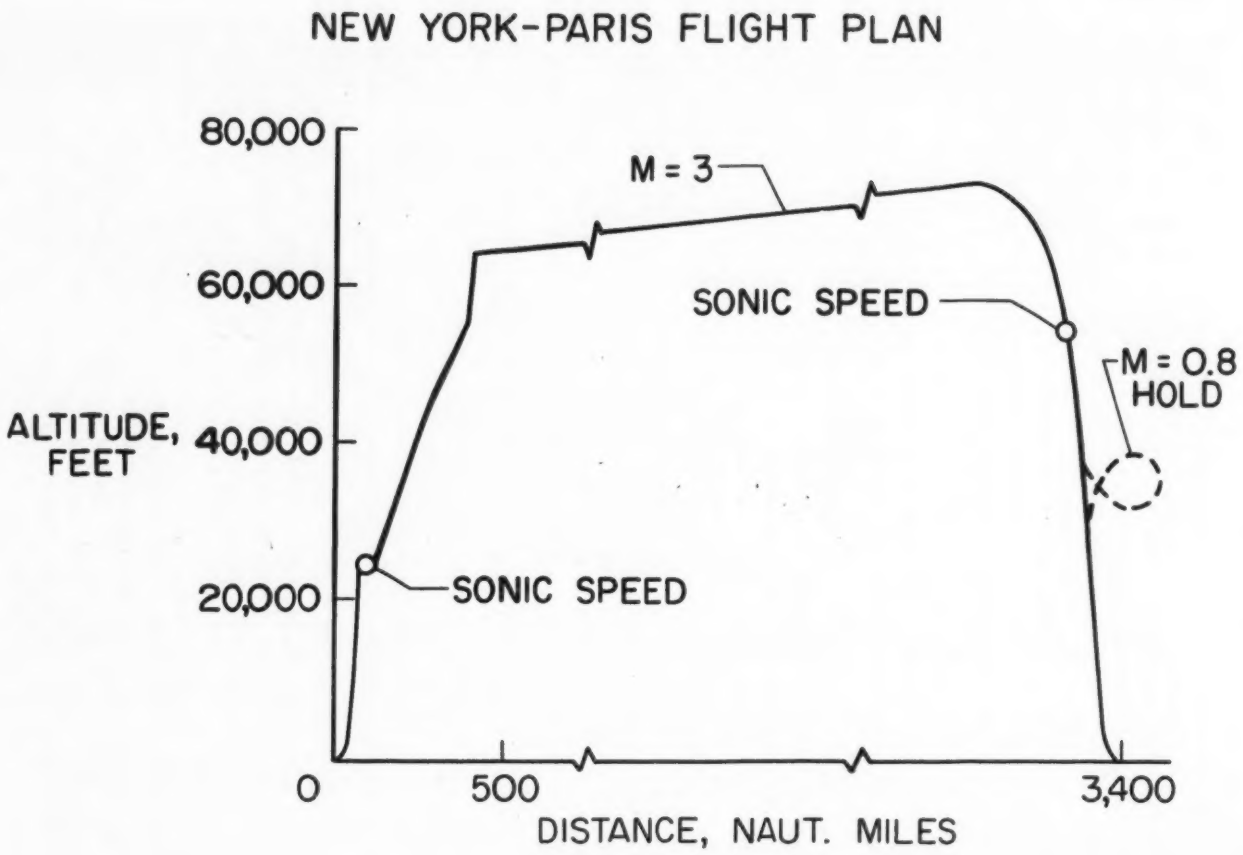

NEW YORK-PARIS FLIGHT PLAN
80,000
60,000
40,000
20,000
ALTITUDE, FEET
M = 3
SONIC SPEED
M = 0.8 HOLD
SONIC SPEED
0
500
3,400
DISTANCE, NAUT. MILES

FIGURE 186

as may be required for altitude separation of east and west bound flights or to avoid areas of atmospheric turbulence, etc.

Again it is emphasized that the efficiency problems of the supersonic cruise have been extensively investigated and to a large extent solved. Investigation of missions such as this show us, however, that there are important problems areas at the beginning and end of the flight that must be dealt with before the craft can become a practical reality. These largely result from the optimization of the aircraft for supersonic cruise to the extent that it no longer performs satisfactorily at subsonic speeds. The importance of this is apparent from the fact that as much as 25 percent of the fuel may be used during these portions of flight. Inefficiency here then makes significant inroads on the cost of operation and/or the payload that can be carried.

VARIABLE GEOMETRY WINGS

A desirable aircraft therefore would be one that altered its shape in such a way as to be more nearly optimum for both speed ranges. Figure 187 shows some of the methods for varying the geometry to accomplish this and also indicates the direction of some of our research effort. Variable geometry is not necessarily a new concept. Transport airplanes have for many years used such devices as slotted flaps (top figure) to extend the wing surface and improve its shape for landing and takeoff. Schemes for applying the same principle to supersonic designs are shown in the lower diagrams. The first shows a droopable wing tip. The tip is up (or extended) for highest area and span, thus giving best subsonic shape, and drooped for supersonic operation where it gives needed directional stability at the expense of additional span and area which it does not need. The middle diagram gives extended span (aspect ratio) and area for subsonic operation by sliding the wing panel outward. The third gives both added area and span (aspect ratio) and in addition decreases the sweep. This is highly desirable also in the interest of high lift and efficiency for landing, takeoff, and hold operations. The deflected tip system on the lower left is probably the easiest to apply from a structural standpoint but gives the smallest improvement. The second presents some obvious structural problems and has been bypassed in favor of the one on the right which has been extensively investigated because of its larger advantages. The mechanical and operational feasibility of this arrangement has been demonstrated in the past by the X–5 airplane project. The mechanism of this early design was somewhat heavy and introduced aerodynamic penalties because the wing had to be translated as well as rotated in order to maintain proper balance. New research into the application of the principle to supersonic transports, however, has shown that severity of the aerodynamic center shift previously associated with wing rotation can be greatly reduced and configurations have been developed that have good stability and control charactertistics as well as efficiency throughout the speed range. Concurrent mechanical studies have also shown that light and efficient pivot mechanisms can be developed.

The application of these principles to a transport design is illustrated in figure 188 which is a line drawing of a model being prepared for test. The outer panels of the wing are set at 67° sweep for supersonic

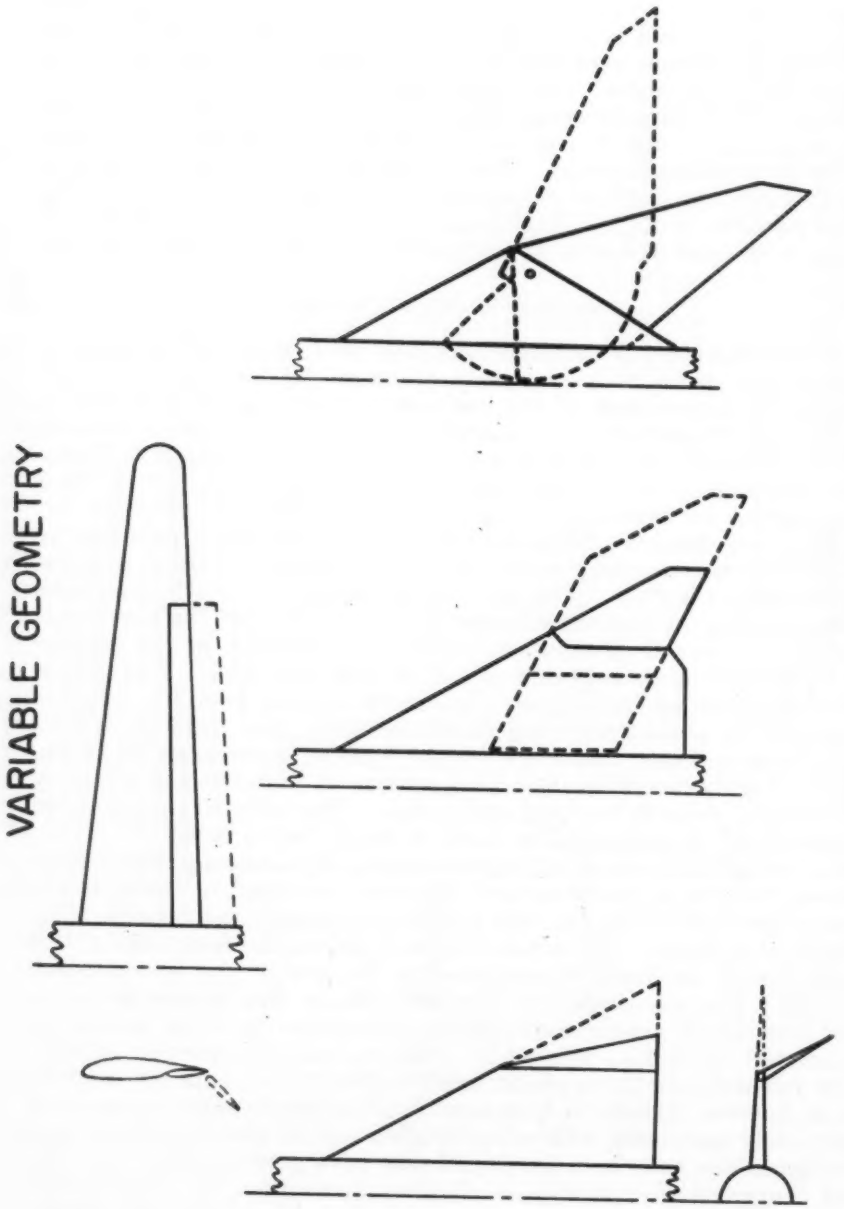


FIGURE 187

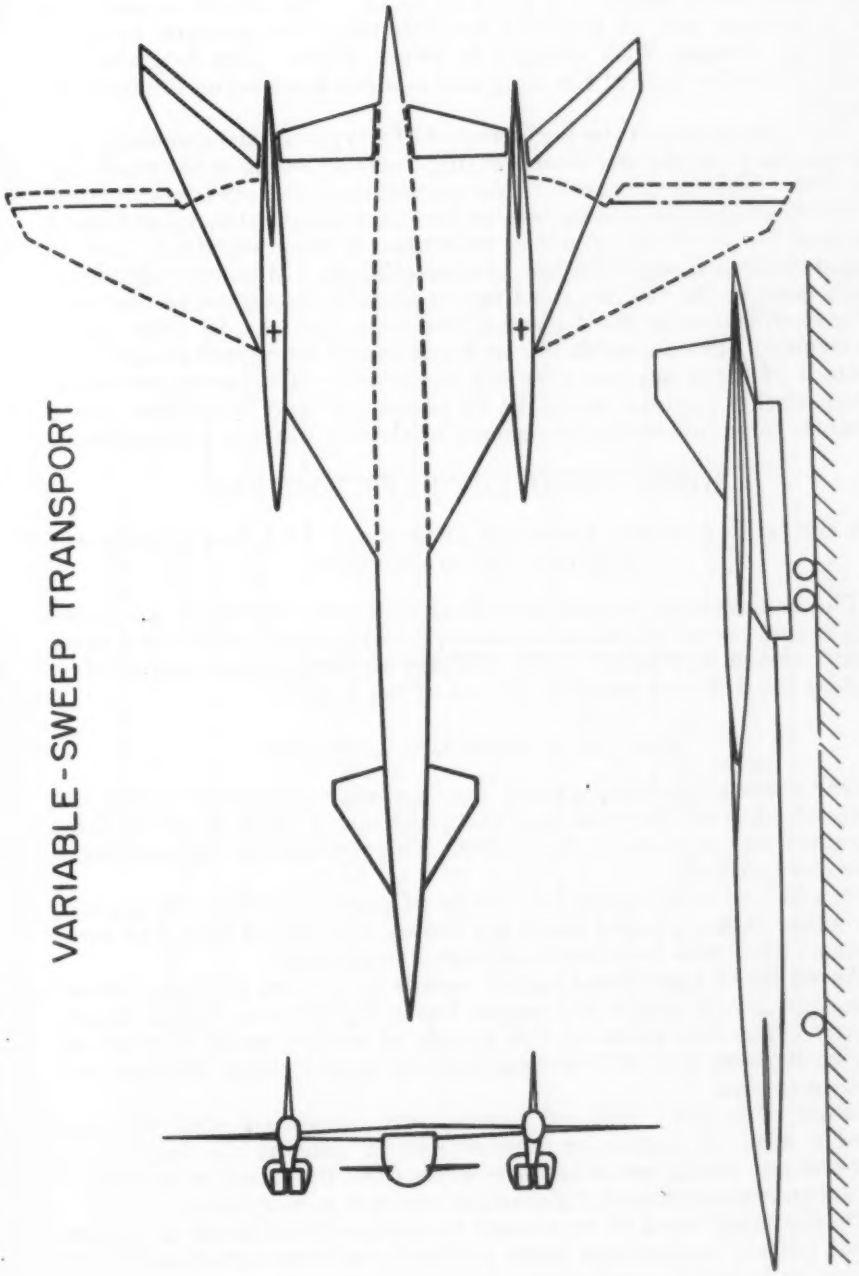


FIGURE 188

flight and are rotated to 27° for subsonic operation. The accompanying aspect ratio variation is from 1.9 to 4.5. The canard is used both as a trimmer and as a means for balancing the airplane to avoid stability changes with changes in sweep angle. The longtitudinal control is at the rear of the wing and ailerons are used on the rotating panels.

The comparison of the performance of a typical fixed geometry configuration with the one incorporating variable sweep is shown in figure 189. This lists several critical performance factors for both types. The takeoff distance can be reduced by 44 percent, the touchdown speed reduced by 30 knots, and the subsonic climbing capability can be maintained to about 9,000 feet greater altitude. Moreover significant reductions in the fuel required for emergency conditions are realized. The significance of the 4-percent fuel reduction can be better given in terms of payload capability in which case it represents almost 7,500 pounds of extra payload that can be carried. The passenger equivalent of this payload would be 33 passengers and at current transatlantic fares this would correspond to about $16,500 in gross revenue.

HIGH-SPEED AIRCRAFT ENGINES

By Bruce T. Lundin, Assistant Director, NASA Lewis Research Center, Cleveland, Ohio

The achievement of satisfactory engines for supersonic airplanes was the subject of an intensive research-development effort for a little over a decade, carried out by the military services, by private industry, and by the different research centers of the NASA.

SUPERSONIC PROPULSION CAPABILITY

Our present capabilities today for supersonic propulsion which has come about from the combined and cooperative effort of all of these organizations is shown in figure 190. This is plotted in terms of flight speed and altitude.

In addition to the operating limits of particular kinds of engines, two other rather general limits are shown, one that is called an aerodynamic limit and the other is an engine stress limit.

As we fly at higher and higher speeds at a given altitude, the air that strikes and enters the engine has a higher and higher kinetic energy. The ram effect of this energy of motion tends to raise the engine stresses, and it is necessary to use progressively stronger and heavier engines.

While this limit will, of course, vary somewhat with the particular kind of engine or application, in general the high-speed, low-altitude conditions below this stress limit line must be avoided if we are to obtain efficient, lightweight aircraft powerplants.

On the other hand, if we atempt to increase the altitude at a given speed, the air becomes less dense and both the thrust produced by the engine and the lift development by the airplane decrease.

These effects conspire in such a manner that effective sustained flight by air-breathing engines is not possible in the high altitude region above this line. So the two lines thus establish this so-called corridor of possible continuous flight.

PERFORMANCE COMPARISON

ITEM	CONV.	VAR. SWEEP
T. O. DIST. OVER 50 FT.	9,000	5,000
$V_{TOUCHDOWN}$ $\alpha = 12°$, KTS	150	120
MAX ALT 1000 I/MIN R/C M=.9	35,000	44,000
T. O. FUEL, 30 MIN TERMINAL HOLD, %	11	7
T. O. FUEL, EMERG. SUBSONIC CRUISE FROM MID RANGE, %	26	20

FIGURE 189

53795 O—60—pt. 2——22

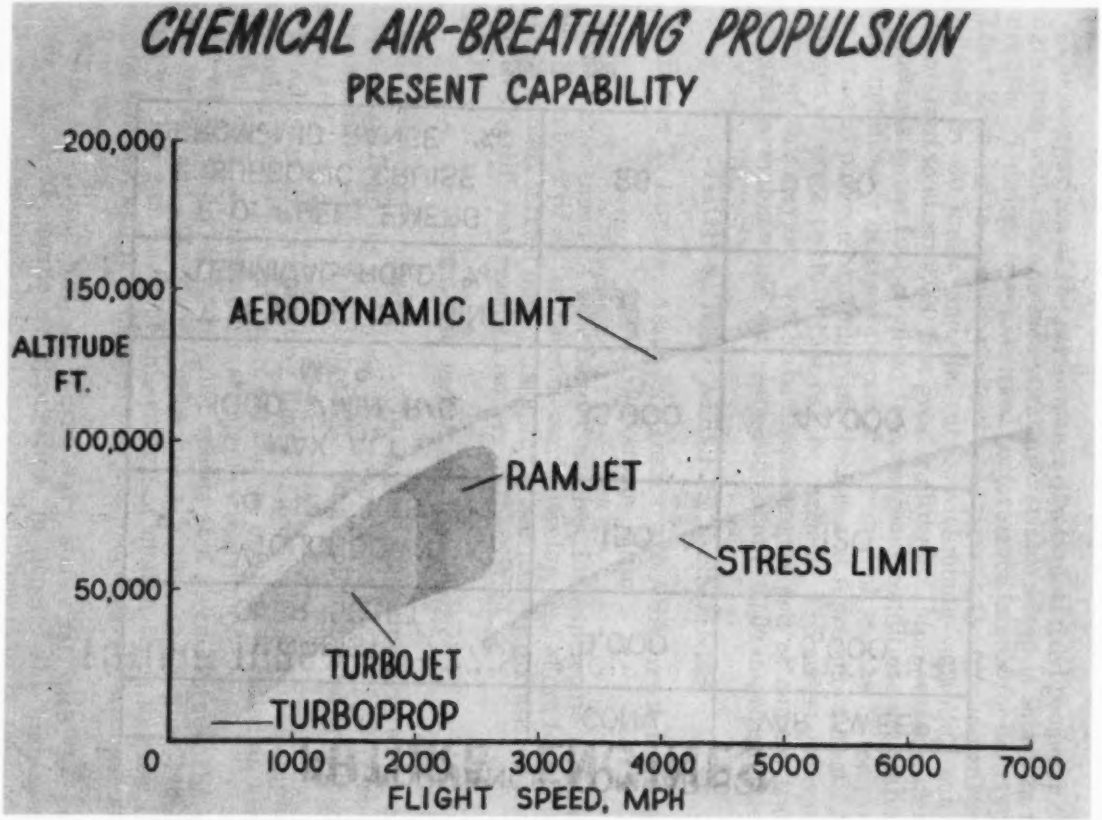

CHEMICAL AIR-BREATHING PROPULSION
PRESENT CAPABILITY
200,000
150,000
ALTITUDE
FT.
100,000
50,000
AERODYNAMIC LIMIT
RAMJET
STRESS LIMIT
TURBOJET
TURBOPROP
0
1000
2000
3000
4000
5000
6000
7000
FLIGHT SPEED, MPH

FIGURE 190

Within these general limits the operating envelope of particular engines will be further defined by their particular design arrangements. These limits are shown for our present turboprop, turbojet, and ramjet engines.

The turboprop, such as used in our present Viscount civil transport, is limited to subsonic speeds of about 400 miles an hour. The turbojet extends this spectrum into the supersonic speed region, with some engines in production development being capable of efficient flight at about 2,000 miles per hour at altitudes of around 70,000 feet.

The ramjet engine, such as used in the Bomarc or Talos missiles, is now undergoing flight development testings at speeds of about 2,000 miles an hour, and the technology necessary to build engines for about 2,500 miles an hour and 100,000 feet in altitude is available.

THE TURBOJET

We can inquire further into the nature of these limits, and particularly what must be done to extend them. Figure 191 shows two engines, one a future turbojet engine that might be used for a speed of about 2,700 miles an hour, and a future ramjet engine that has been designed for a speed of 5,000 miles an hour.

In any turbojet engine, four processes are necessary to develop a propulsive thrust. First, the air must be inducted into the engine in an appropriate inlet system. This air must then be successively increased in pressure, which is the function of the inlet and the compressor, and heated to a high temperature in the combustion chambers.

Part of the energy of these hot gases is used by a turbine to drive the compressor. So we then have in the rear portion or the tailpipe of the engine a high-pressure, high-temperature gas. This relatively slow-moving but high-temperature gas is then accelerated to a high velocity and ejected by an exhaust nozzle. It is the reaction to this increase in velocity of the air going through the engine or the pushing of the engine on the gases, that makes the propulsive thrust.

THE RAMJET

The ramjet operates in a very similar manner to the turbojet, except that in this case the entire pressure rise of the air prior to heat addition is accomplished in the inlet by virtue of the ram effect. No compressor and turbine assembly is therefore required, and considerable simplification results.

The absence of this compressor-turbine, however, means that this engine cannot produce thrust at takeoff and low-speed conditions, and so it has to be boosted to operating speeds by other devices, usually rockets.

PROBLEM AREAS

Many difficult problems exist if we are to obtain a 2,700-mile-per-hour turbojet engine. It can be stated that the research knowledge necessary for this development currently exists. The development of this technology has been for the most part a struggle with the high-temperature environment of high-speed flight.

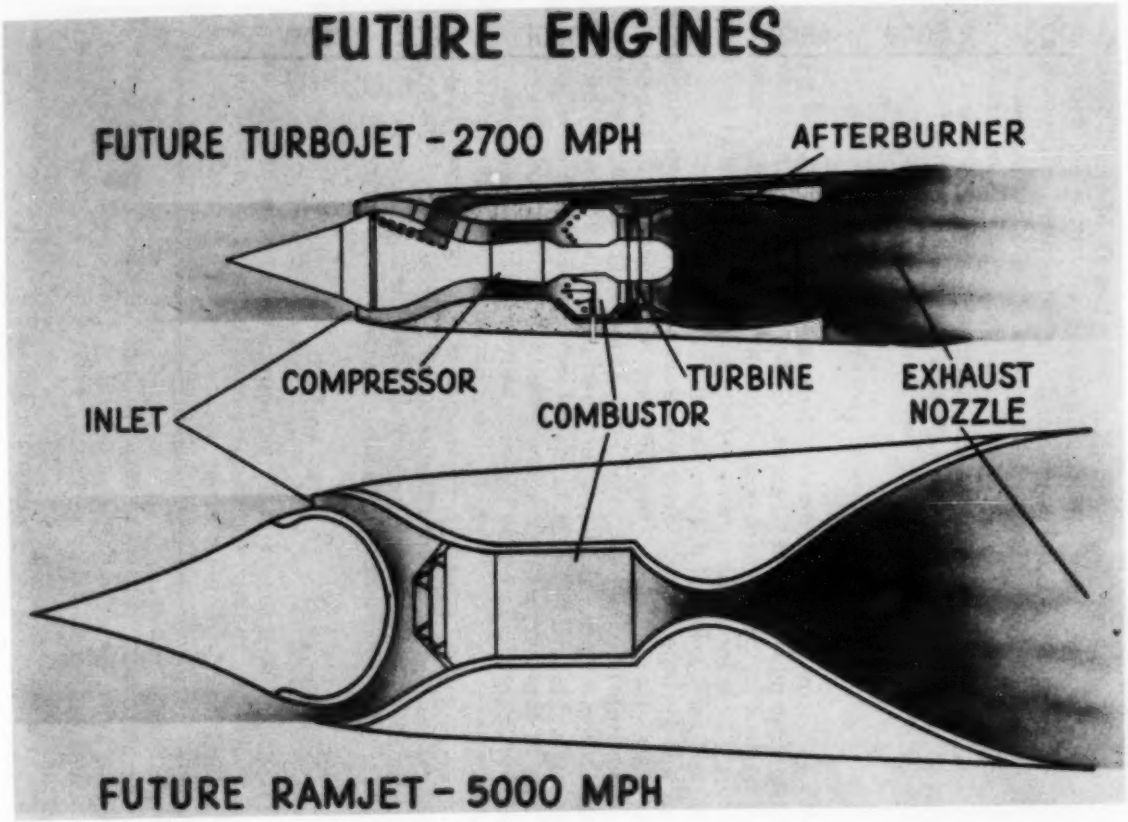

FUTURE ENGINES
FUTURE TURBOJET - 2700 MPH
AFTERBURNER
COMPRESSOR
TURBINE
EXHAUST NOZZLE
INLET
COMBUSTOR
FUTURE RAMJET - 5000 MPH

FIGURE 191

For example, at a speed of 2,700 miles an hour, the inlet air temperature is about 1,200° F., and increases very rapidly with further increases in flight speed. These high temperatures introduce two basic difficulties.

TEMPERATURE

These are, first, the obvious one of the temperature limits of the materials that are used; and, secondly, the necessary compromises in designs that are necessary to get an engine which will work well at both an inlet temperature of 1,200° F. and at the very low temperatures of low-speed flight.

Considering the material temperature limit, it becomes necessary at speeds in excess of 2,700 miles an hour to cool the compressor and the turbine by circulating fuel or some other coolant through all of their parts.

This can be done. However, the only place to which this heat may be rejected is into the fuel itself. Now, the amount of heat that may be rejected to the fuel is, of course, limited, and we reach a limit of practical fuels for jet engines at about 3,000 miles per hour.

Higher speeds are certainly more likely to be obtained with the ramjet type of engine. Here again the dominant problem in a high-speed ramjet engine is that of enabling the engine to endure the very high temperature of high-speed flight. Some idea of what these temperatures are is shown in figure 192, where the temperature is plotted for different flight speeds.

The upper curve is the temperature that the walls of the combustion chamber are exposed to, and the lower curve is the temperature of the walls of the inlet of the engine.

Also shown are the temperature limits of some available and foreseeable materials. Present steels and high-temperature alloys are practicable for only the inlet diffuser for speeds in the region of about 3,000 miles per hour.

A ceramic-coated steel or a coated molybdenum will permit increases in speed of perhaps a thousand miles an hour. At 5,000 miles an hour, however, these temperatures range from about 5,000° F. in the inlet diffuser to 6,000° F. in the combustion chamber wall, so it is evident, therefore, that speeds in this range will require very special cooling of all parts of the engine.

So again the problem of speed limits resolves itself into this heat-absorbing capability of the fuel, and some of these limits are in figure 193 again in terms of altitude and flight speed, with two curves representing a corridor of possible continuous flight.

FUEL

With conventional jet fuels and present steel construction, speed capabilities of about 3,500 miles an hour are indicated. Pertinent to this limit with hydrocarbon fuel is the fact that these fuels may only be heated to about 600° or 700° F. before they crack and form undesirable gums in the engine fuel system.

A cleaner fuel which can be heated up to higher temperatures and thus do more cooling is methane. If this fuel, normally a gas, is refrigerated and liquefied and used for a high temperature alloy engine, a speed of a little over 4,000 miles an hour should be possible.

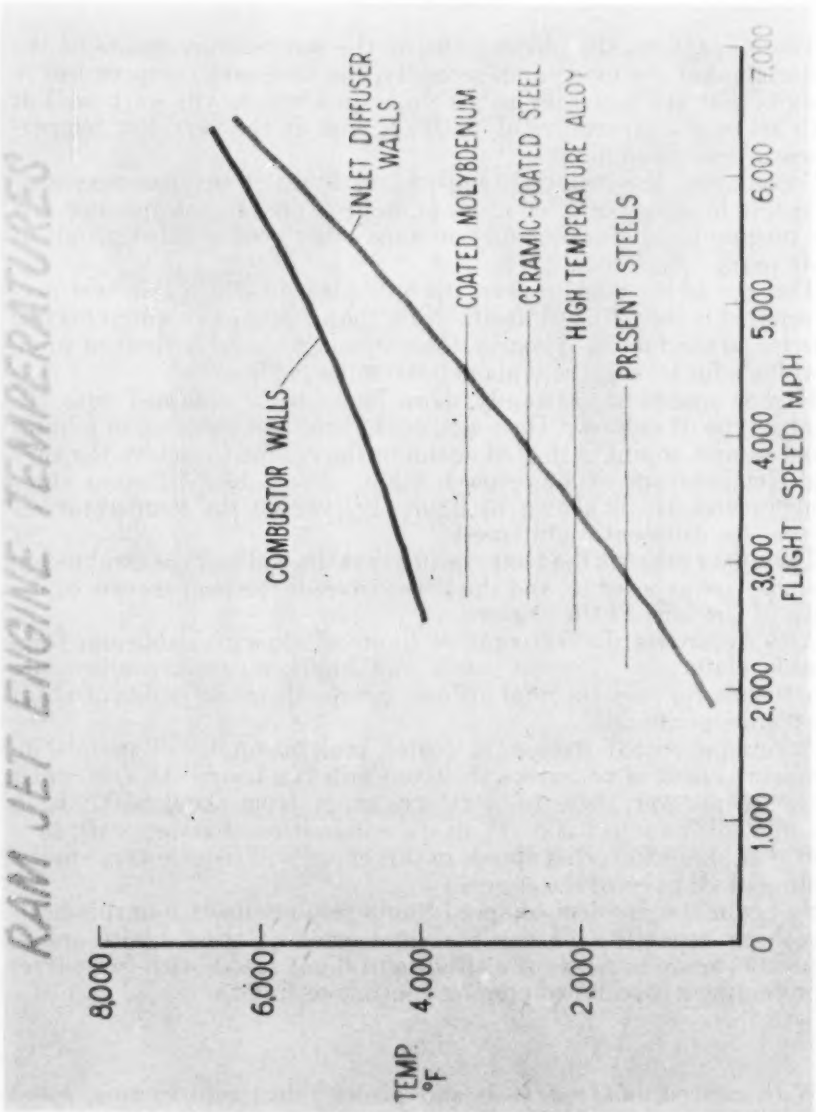

RAM JET ENGINE TEMPERATURES
TEMP °F
8,000
6,000
4,000
2,000
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
FLIGHT SPEED MPH
COMBUSTOR WALLS
INLET DIFFUSER WALLS
COATED MOLYBDENUM
CERAMIC-COATED STEEL
HIGH TEMPERATURE ALLOY
PRESENT STEELS

FIGURE 192

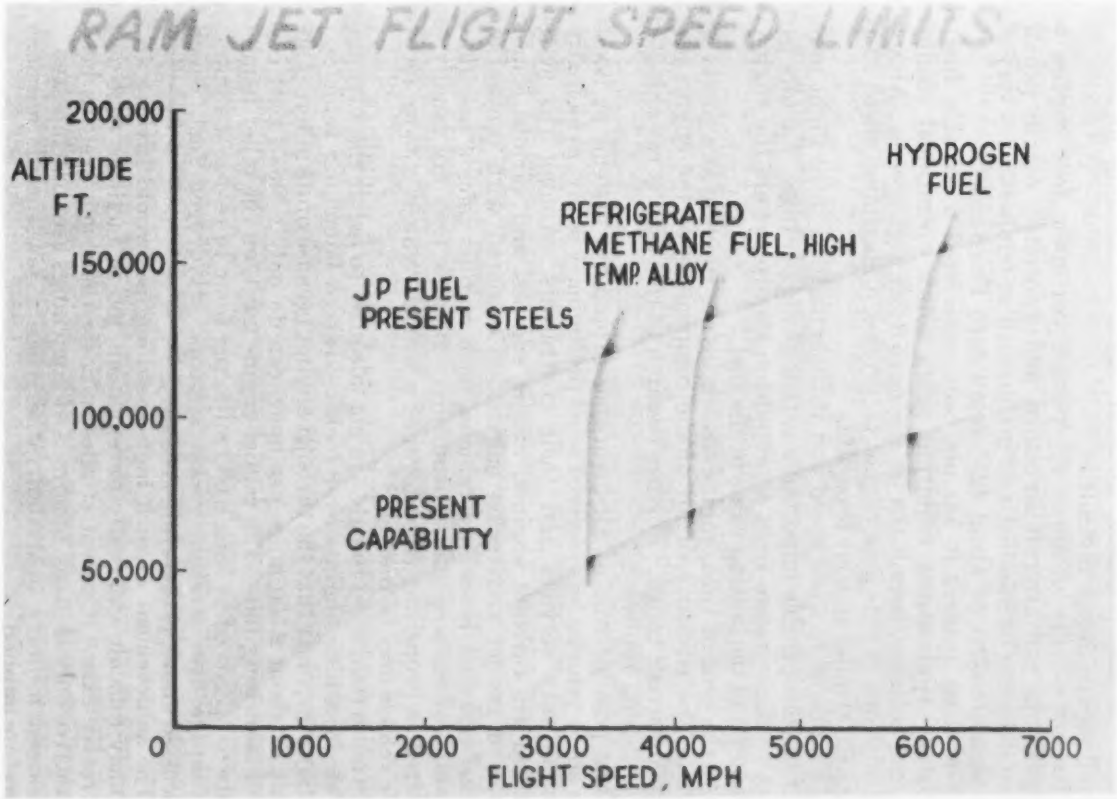

RAM JET FLIGHT SPEED LIMITS
200,000
ALTITUDE
FT.
150,000
100,000
50,000
0
1000
2000
3000
4000
5000
6000
7000
FLIGHT SPEED, MPH
HYDROGEN
FUEL
REFRIGERATED
METHANE FUEL, HIGH
TEMP ALLOY
JP FUEL
PRESENT STEELS
PRESENT
CAPABILITY

FIGURE 193

Higher speeds require the use of liquid hydrogen fuel. Liquid hydrogen is outstanding in regard to both cooling capacity and energy content. Compared to conventional jet fuels, it can do about 10 times as much cooling, and it has an energy content nearly three times as great. It also possesses, however, some outstanding logistics and handling and design difficulties.

Its low density of about 4½ pounds per cubic foot implies very large tanks and aircraft structure, and associated weight penalties. Also it has to be handled and maintained at temperatures very close to absolute zero, or about 425° below zero Fahrenheit.

For these reasons it has not been considered a suitable fuel for military applications requiring short notice operational readiness. It can, however, permit the jet engine to fly at high speeds. Although calculations in this area cannot be precise, a maximum speed of perhaps 6,000 miles an hour is possible.

In addition to these speed and altitude limits, a third flight parameter of considerable importance is that of flight range. Factors pertinent to flight range from a propulsion standpoint are the engine efficiency and the heating value of the fuel.

At the present time, engine efficiencies are running at a pretty high level. The efficiency of all of the components of the engine are in the 90 percent range. Further research in this area is rewarded with diminishing returns.

The possible role of air-breathing propulsion systems as boosters for space vehicles has received some preliminary study, principally by the military services and their contractors. Among the systems studied are turbojet engines, ramjet engines, and various combinations of ramjet and rocket engines. Compared with conventional, rocket-powered launching vehicles, such engines offer a possible advantage of reduced fuel expenditure. Because they are usually considered as propelling some form of a winged vehicle, a more recoverable vehicle may be possible.

Studies conducted to date are not adequate to define the advantages of air-breathing engines over rocket-powered launching vehicles. It is, however, clear that the turbojet engine, because of its inherent speed limit of about 2,500 miles per hour, can do only a small part of the total launching job. The ramjet engine must, on the other hand, operate to speeds of at least 6,000 miles per hour to realize a significant advantage over straight rocket systems. Hydrogen fuel, which is discussed above, is therefore necessary.

The achievement of such high-speed engines would involve an extremely difficult and costly development job in facilities that do not currently exist. Current studies indicate that such systems become attractive only if many hundreds of launchings are contemplated. A sustained military operation rather than a few specific missions is therefore implied.

The advantages of the air-breathing launching systems are in the realm of economics rather than in performance characteristics. They therefore become a practical possibility only when space operations exist on a regular, widespread, and sustained basis. The economic gains that may be afforded may become important enough at some future date, however, to justify the development and operation of these more complex systems, particularly if effective recovery of conventional rocket-powered vehicles proves difficult.

HYPERSONIC VEHICLES

By John V. Becker, Chief, Aero-Physics Division, NASA Langley Research Center, Hampton, Va.

By usage, hypersonic has come to mean any speed greater than about 1 mile per second. Satellite vehicles travel about 5 miles per second. They are one of the class of manned hypersonic vehicles. Another type of hypersonic vehicle of the manned type in which we are interested is the Dynasoar class.

AERODYNAMIC PROBLEMS

For a vehicle which has to carry its own fuel and its own propulsion system and cover the whole range under its own power, we need a design similar to the B–70. This is a very large airplane because it has to have enough thrust, enough power, to get off the ground with the large fuel load.

In the case of the hypersonic glider, the glider itself carries no part of its propulsion system. The propulsion is provided by a large booster of the ICBM class, and the engine then falls off after giving the glider enough speed to coast the entire distance of its flight. Because it does not have to carry any propulsion equipment, and because it carries no fuel, it is a small relatively simple vehicle aerodynamically speaking as compared to the older type.

To achieve the long ranges in which we are interested, we have to boost our glider to extremely high speeds. To achieve really long ranges you have to have a speed that is getting up close to the satellite speed. So from the research standpoint we are interested in getting into that extremely high-speed range, whereas previously we were concerned with aerodynamics at much lower speeds.

The higher the speed of the glider, the higher the altitude at which it starts its flight. If it goes all the way to satellite conditions, it is essentially out of the atmosphere. For the global range we operate in the upper fringes of the atmosphere. The main problem area is aerodynamic heating.

In the field of stability and control for these gliders, the problems arise from two main sources. First, the glider has to cover an extreme speed range starting off near the satellite speed, gliding down through the atmosphere, and finally landing. It has to be stable and controllable in all of those regimes.

Corresponding to the wide speed range, we have a large range of altitude. At the highest altitude we have not enough aerodynamics to control the vehicle and we use what is called reaction controls.

During boost there is a special class of stability and control problems that we are not familiar with for the ordinary aircraft.

One of the main problems in an airplane of the B–70 type was drag reduction. This is a problem for the gliders, but to a reduced extent.

If we consider a 5,000-mile-range glider, its initial speed will be high enough so that as it circles around the curved path it has a centrifugal lift force. Thus, we don't have to provide all of the lift aerodynamically. There is enough aerodynamic force here to show that we are concerned to some extent with drag, and we have to use a design which has low drag. It has to be very long, slender. It has

to have sharp leading edges. It has a long slender fuselage and has to have controls.

Now, if we are aiming for global range, the centrifugal lift that comes from flying around the curved path is so large that the aerodynamic forces we are concerned with become very small. With these small aerodynamic forces we are less concerned about the drag and we can design vehicles which have in general short stubby shapes with blunt leading edge radii which are better structurally.

If we are trying for the extreme ranges on the order of global, we have really a different kind of vehicle than if we are aiming for the shorter ranges of up to 5,000 miles. The Dynasoar vehicle is actually in between these two extremes. It will start with short ranges and its range can gradually be increased.

DIRECTIONAL STABILITY

The stability problems of these vehicles is illustrated by the problem of directional stability. By directional stability we means the ability of the vehicle to keep itself pointed along the desired flight path. If the directional stability diminishes too much, the glider will tend to yaw abruptly and this may be catastrophic as it was in the case of the X–2.

Many airplanes tend to have this stability characteristic. That is, if the speed is increased far enough, we reach a point of directional instability. Now, in these hypersonic gliders, by proper aerodynamic design it appears that this trend can be avoided, and that stable configurations can be achieved all the way up to the very high speeds that we are interested in.

The X–15 will contribute importantly in flight research by filling in a part of this unknown region.

AERODYNAMIC HEATING DURING DESCENT

Heating is the main problem during descent. We have considered some actual trajectories in figure 194 which our gliders might reenter the atmosphere. These are presumed to be global-range gliders descending to a landing. The glider presumably came all the way around the earth in the outer fringes of the atmosphere, and in its last few thousand miles of flight it will reenter the atmosphere.

We may follow different paths in reentering. If we operate the glider at a low-lift coefficient or a low attitude, it will glide along a path such as shown and will have a relatively long range in the atmosphere and a long time in the high heating region.

If we fly at a high angle of attack with more drag, the glider will come down more quickly, but it will have to pass through the same point of critical heating which occurs at about 15,000 miles per hour.

It will be in this situation a shorter time than if it glided with low drag. In general, in the design of these gliders the structure has to be designed to cope with this critical point here, and at all other points in the glide the structure has a less serious problem than at that particular point.

Presumably these wing vehicles will carry landing gears as in the case of Dynasoar, and they will be able to make a conventional air-

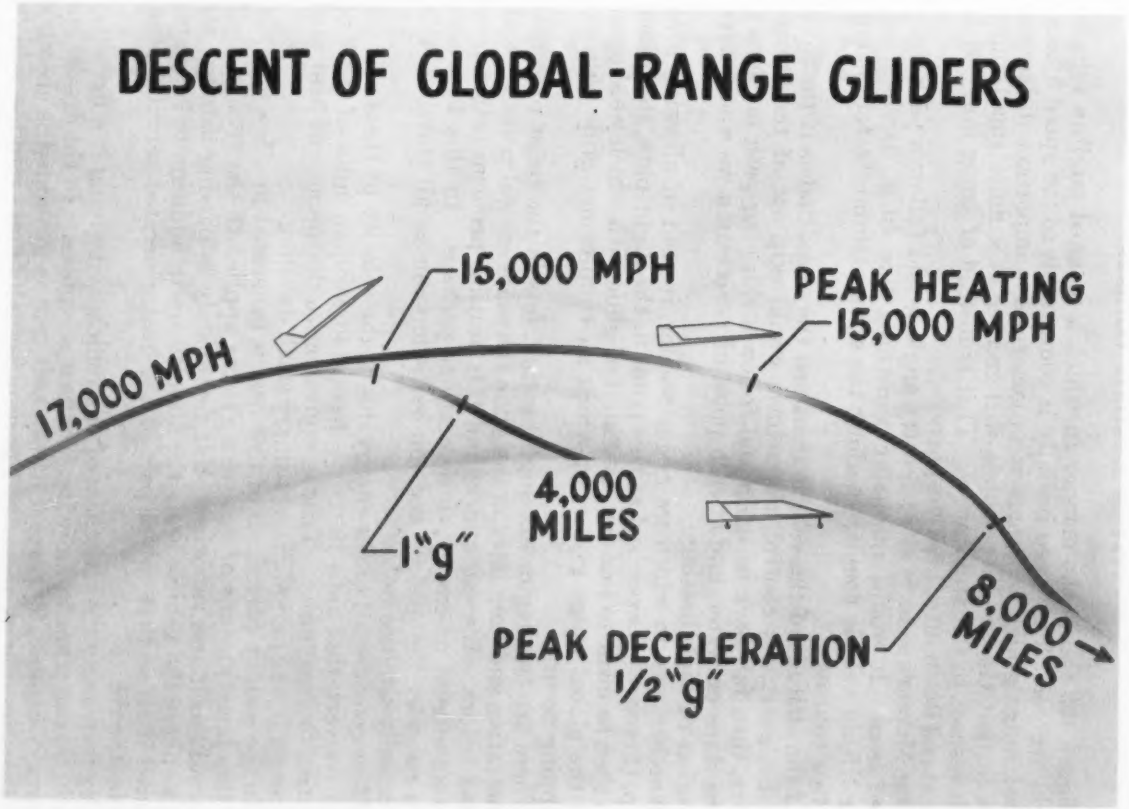

DESCENT OF GLOBAL-RANGE GLIDERS
15,000 MPH
PEAK HEATING
15,000 MPH
17,000 MPH
4,000
MILES
1"g"
8,000
MILES
PEAK DECELERATION
1/2"g"

FIGURE 194

port landing. The accelerations encountered by these vehicles are quite low, of the order of a half to 1 g. acs compared to perhaps 8 g. for our Mercury capsule.

REENTRY OF SATELLITE VEHICLES

Figure 195 shows the manner in which a manned satellite vehicle might reenter. The speed initially is comparable to the speed of our global range glider, but there is in general one important difference here in that the satellite vehicle will reenter at a finite small angle with respect to the atmosphere. That is instead of being tangential, it is aimed down into the atmosphere.

Our Mercury vehicle at 3° reentry angle would follow a path indicated here. It would encounter something like 10 g. deceleration. Our lifting vehicle coming in along the same path might follow one of two courses.

If the attitude of the vehicle remained the same, that is if the pilot did not exert any control, the vehicle would skip out of the atmosphere, then fall back in again and follow a skipping path much as a stone skips on water, and at each point of penetration we would have a region of high heating.

Another way in which we might reenter, instead of allowing it to skip, if control is exercised at this point in the flight path, the glider can then be made to join the same kind of glide path which we showed for the global range glider, in which an equilibrium glide with no skipping occurs.

There are two regions of high heating, one in the point of initial penetration and then later in the glide the same critical point that we noted before. We can understand this heating problem better from the standpoint of energy considerations perhaps. In this figure we also consider the gliders and the ballistic vehicles all starting with essentially satellite velocity.

If we consider all of the energy due to the velocity of these vehicles and convert that into heat, we have 140 million units of heat or British thermal units. That is equivalent to the amount of heat used during a 1-year period in an ordinary small dwelling.

In the reentry period, all of this heat is generated in a few minutes. If this large amount of heat energy was applied to the vehicle itself it would melt and vaporize. But fortunately in passing through the atmosphere the vehicle heats the atmosphere in addition to becoming heated itself so that only a part of the heat generated actually penetrates the vehicle.

By increasing the bluntness of our vehicle and giving it a flat entry path, we can transfer more heat to the atmosphere. In the case of our Mercury capsule, 99 percent of the heat that is generated is absorbed by the atmosphere, and only 1 percent actually flows into the vehicle. In relation to the amount of heat that we can absorb readily in the metal skin of the Mercury vehicle, approximately 10 percent, by devoting 10 percent of the weight of this vehicle to heat protection, it can survive the reentry. But if we look at our winged machines which have much larger frictional areas, they are less blunt, the heat loads here are so high that they cannot possibly be absorbed in the metal, and some other mechanism has to be used for these winged airplanes to enable them to survive reentry.

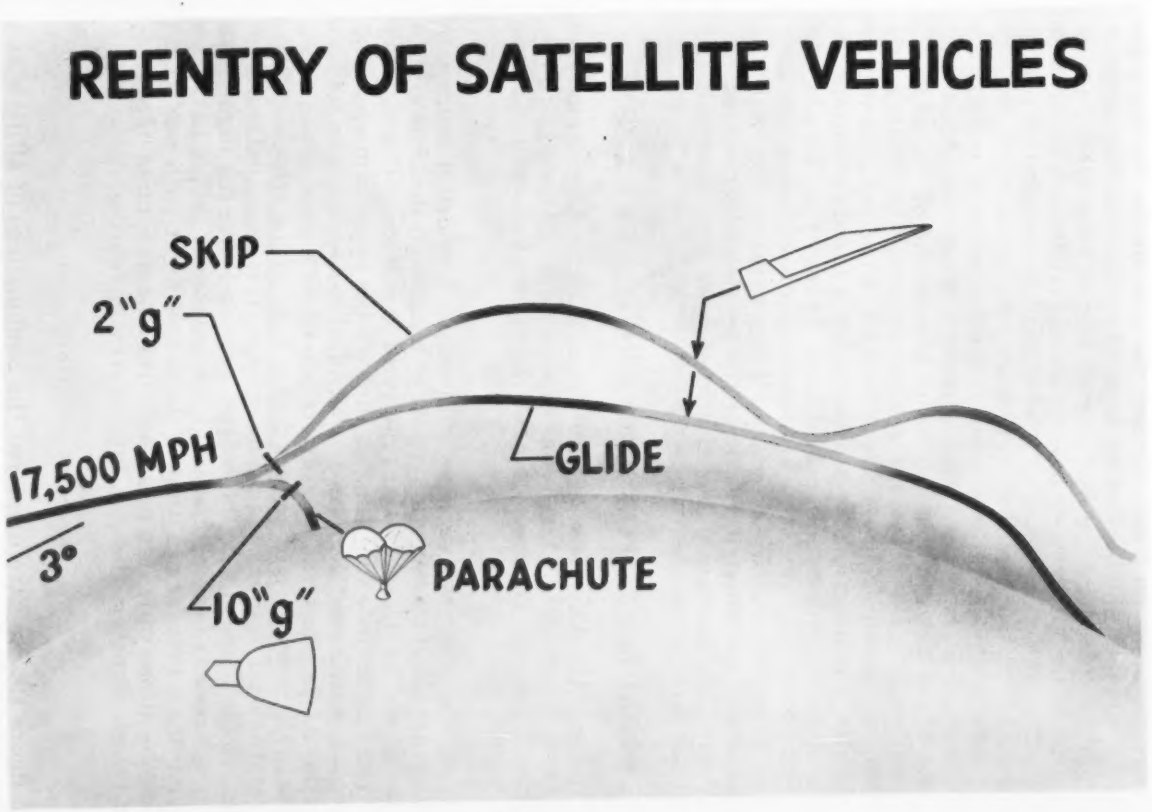

REENTRY OF SATELLITE VEHICLES
SKIP
2"g"
17,500 MPH
3°
10"g"
GLIDE
PARACHUTE

FIGURE 195

The mechanism that is used is radiation. Heat is radiated away from the metal skin provided we let the skin get hot enough. This requires metal temperatures of the order of 2,000° over much of the vehicle, and it presents a very serious design problem.

At critical points on these vehicles, the nose of the fuselage, the wing leading edges, and the leading edges of the controls, the temperature required to radiate the heat is even higher than 2,000°, and in these areas of the airplane we have to use materials such as ceramics or ablating materials or something other than the superalloy metals.

It should be noted here that significant progress toward the solution of these problems has been made. Most noteworthy perhaps are the advances that have been made toward a more complete understanding of the flows and heat transfer phenomena on wings of the type employed in the Dynasoar vehicle concept. In another area methods of maneuvering manned vehicles have been developed analytically which permit large reductions in the decelerations encountered in the steeper entries and large increases in the width of the corridor within which an approaching space vehicle must fly in order to achieve a successful entry. These advances, together with those described elsewhere in relation to materials and structures, constitute a marked increase in technical confidence level for the design of manned reentry vehicles.

STRUCTURES FOR HYPERSONIC VEHICLES

By Roger A. Anderson, Head, Structural Configurations Branch (Formerly Airframe Components Branch), Structures Research Division, NASA Langley Research Center, Hampton, Va.

During the past year we have witnessed a heightened interest in vehicles capable of transporting a man at high speed in orbits around the Earth and in flights to the vicinity of the Moon. During their return to Earth, these vehicles pass through the upper atmosphere at hypersonic speed and perform a controlled maneuver which slows them down. In effect, the atmosphere is used as a speed brake which results in the generation of a great deal of heat on the vehicle surface. The total amount of heat and the rate at which it is generated is related to the vehicle shape and to the control exercised over the flight path during the reentry braking maneuver. A number of people have been studying these two factors, vehicle shape and flight path control, to find combinations which are reasonable from the standpoint of providing a vehicle structure that can survive reentry heating.

REENTRY HEATING

On figure 196 we have displayed the combinations of altitude and speed at which flight could take place within the Earth's atmosphere. The area in the lower left-hand corner defines present experience with manned aircraft. This experience is limited to altitudes of little more than 20 miles and speeds of about 2,000 miles per hour. The remaining curves show the temperatures created in vehicle structures as a consequence of the aerodynamic heating associated with hypersonic speeds.

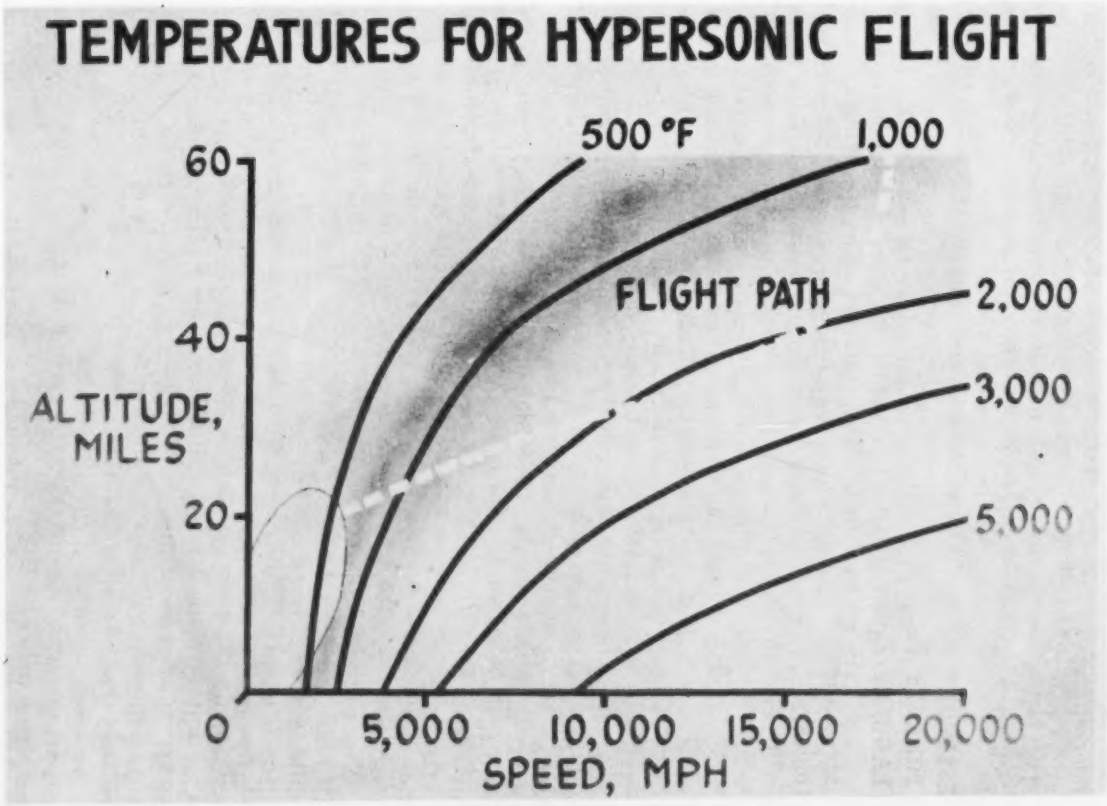

TEMPERATURES FOR HYPERSONIC FLIGHT
500 °F
1,000
2,000
3,000
5,000
FLIGHT PATH
60
40
20
0
ALTITUDE, MILES
5,000
10,000
15,000
20,000
SPEED, MPH

FIGURE 196

The limitations of present structural materials prevent us from penetrating very deeply into this hot zone; hence, hypersonic flight operations are likely to be confined to a narrow corridor following a path such as that shown in figure 196. The region of most severe aerodynamic heating is encountered between 12,000 to 15,000 miles per hour. Lifting vehicles that exceed these speeds, such as those returning from orbit, will spend several minutes passing through this region of critical heating during a return to Earth landing. New types of structures that can survive these heating conditions have been undergoing tests.

STRUCTURAL APPROACHES

In general, these new structures are of two basic types. In one approach we cover the vehicle structure with tough plastic materials which are designed to absorb heat by melting and vaporizing in a controlled manner. This approach is suitable for compact vehicles such as the Mercury capsule, which flies a simple ballistic path during reentry and decelerates quite rapidly. Work is continuing on this approach to extend its application to vehicles of slightly different shape in which greater control can be exercised over the maximum deceleration. The other basic structural approach is to build vehicles of metallic and ceramic materials which can withstand high temperatures without melting and which dissipate heat by radiation. This approach is feasible only for vehicles which utilize an appreciable amount of lift to slow down rather gradually, and which have large surface areas in relation to their weight.

We have built a number of models of these radiating structures to study their behavior in more detail. One of these models is illustrated in figure 197. At the top we show the structure during manufacture. As may be seen, extensive use of corrugated metal is made in order to permit accordion-type movements to occur in the various parts as the structure is heated. These corrugations are supplemented with expansion joints between skin panels which permit larger movements due to thermal expansion. Although this construction would appear to lead to an excessive amount of structural flexibility, tests have shown that a vehicle designed in this manner has the necessary stiffness and strength to survive both the heating and loading encountered during the reentry manuever. These tests were carried out in the laboratory with a large radiant heating facility, which subjects structures to temperatures up to 2000° F. Tests on this and similar types of models will continue during the coming year to provide the required design data for industry.

MATERIALS PROBLEMS

The principal block to rapid progress in these radiative structures is the poor quality and limited availability of materials satisfactory for use at temperatures in excess of 2000° F. Therefore, a good share of our research program is devoted to tests to determine the structural potentiality of available samples of high temperature materials and to research to overcome problems that occur in the use of these materials. Some of this work is illustrated in figure 198.

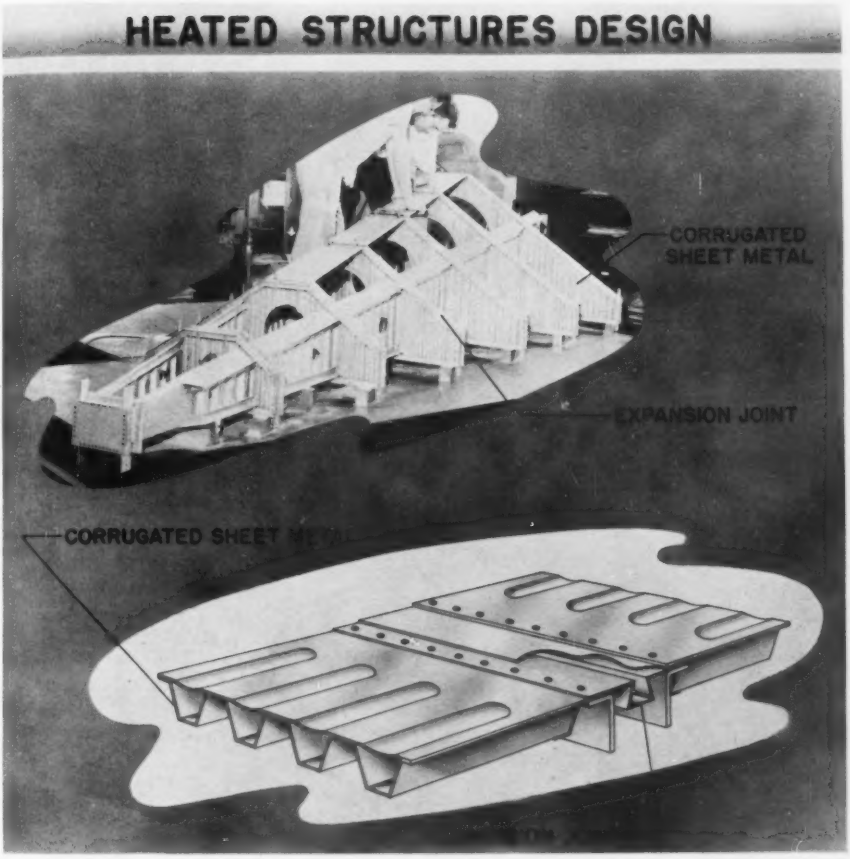

HEATED STRUCTURES DESIGN
CORRUGATED SHEET METAL
EXPANSION JOINT
CORRUGATED SHEET METAL

FIGURE 197

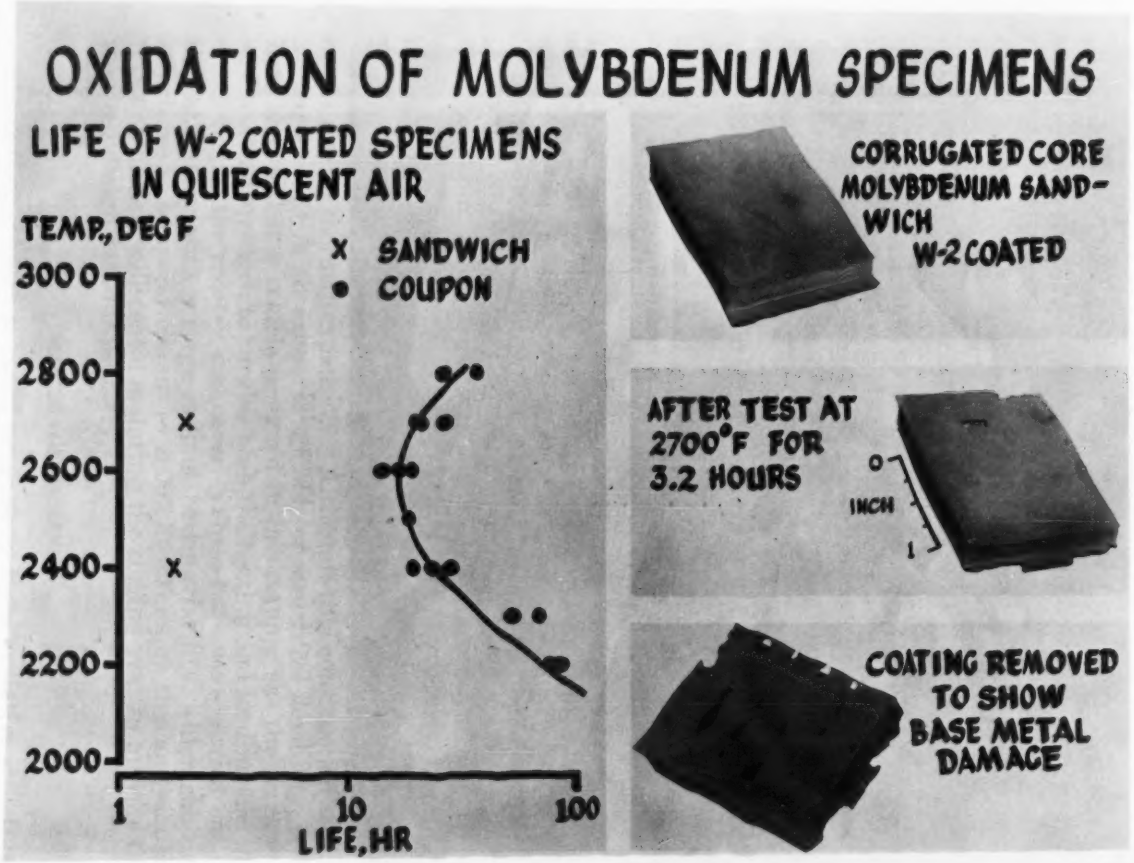

OXIDATION OF MOLYBDENUM SPECIMENS
LIFE OF W-2 COATED SPECIMENS IN QUIESCENT AIR
TEMP., DEG F
X SANDWICH
• COUPON
3000
2800
2600
2400
2200
2000
1
10
100
LIFE, HR
CORRUGATED CORE MOLYBDENUM SANDWICH W-2 COATED
AFTER TEST AT 2700°F FOR 3.2 HOURS
0
INCH
1
COATING REMOVED TO SHOW BASE METAL DAMAGE

FIGURE 198

Here we show some of the test data we have obtained on structural samples of molybdenum alloy. The most notable difficulty with this material is that it oxidizes very rapidly at elevated temperature unless the surface is sealed with special coating materials. One of the more promising coatings that has been developed is known commercially as W–2, and the performance of molybdenum with this coating is illustrated on this figure. It shows that when material samples are exposed to high temperatures between 2000° and 3000° F. they achieve a useful life of between 10 and 100 hours. When fabricated into structures, lifetimes of the order of 2 to 3 hours have been achieved, as indicated by the "X" points. Although such lifetimes are not as long as we ordinarily desire for structures, these tests indicate a good potential for reentry vehicles which are exposed to high temperatures for less than 1 hour.

An interesting aspect of this oxidation problem is illustrated by the picture at the right in figure 198. The specimen before test is shown at the top and at the middle we show the appearance after test. Small areas of the structure show attack by oxidation. At first glance this did not appear catastrophic but subsequent examination of the structure showed that it was rather completely shot through with holes. These large holes result from minute pinholes or cracks in the coating which are difficult to eliminate. Oxygen molecules leaking through these holes attack the metal in much the same way that termites make an unseen attack on the interior of a piece of wood. Despite this difficulty of achieving a long lifetime with molybdenum structures, we are confident that with a continuation of the research now going on, a satisfactory material for reentry structures will be achieved.

One of the other factors we are concerned with in the use of high temperature metals is the poor availability of thin sheets of these materials in the sizes and with the quality required for structural application. I wish to emphasize that the size of these specimens is only 2½ inches square and is an indication of the difficulty we have in obtaining the kind of material we need to make more extensive tests. We do not need massive sheet rolling programs of the type initiated for titanium, but we do require small facilities in industry capable of producing small quantities of high quality material. The metals of most interest to us in this high temperature class are molybdenum, columbium, tantalum, and tungsten. These materials play a key role in the construction of manned reentry vehicles of the type which permit reentry with low deceleration forces and which possess a high degree of maneuverability for selection of a landing site upon return from orbital missions or space journey.

Another area in which considerable progress has been made is the difficult problem of utilizing nonmetallic materials such as graphite and ceramics for the construction of leading edges components. Large hot air jet facilities have recently come into operation for testing promising structural designs for these highly heated components. It has been demonstrated that new forms of graphite with improved oxidation resistance are capable of withstanding the reentry environment. Leading edges of graphite are currently undergoing tests. Similar tests are planned on leading edge and stagnation area structure utilizing insulating shields of foamed ceramic materials.

Ground research will be continued on new types of high temperature structure with the objective of exploiting the potential of new materials insofar as they are available. During the coming year we expect that initial flight tests at reentry velocities will be performed with unmanned experimental vehicles to further check the performance of these advanced structures.

HUMAN PROBLEMS IN OPERATION OF HIGH-SPEED VEHICLES

By Hubert M. Drake, Assistant Chief Research Division, NASA Flight Research Center, Edwards, Calif.

This section pertains to the pilot and how he works together with his machine, covering a few of the human problems involved in the operation of high-speed vehicles.

The NASA has been working in all these fields for a considerable length of time.

HUMAN VERSUS AUTOMATIC CONTROL

One important problem is the question of the proper tradeoff between the utilization of a pilot and automatic piloting equipment.

The automatic equipment is attractive because it has strength that the pilot does not have, it is quicker in response than he is, and it is more precise in its response. However, automatic equipment has a considerable number of what one might call frailties: (1) It is extremely complex; (2) it lacks reliability; (3) it is expensive; and (4) it needs to be developed.

From the foregoing it is apparent that automatic equipment will always come later than the human pilot in the development cycle. Thus, the question of how much automaticity to incorporate in a given airplane or space vehicle involves two elements, the present state of the art of automatic controls systems and the capabilities of the human pilot.

NASA is conducting research in both of these fields; that is, exploring means of improving automatic equipment, its capabilities, and also exploring the limitations of the human pilot and his abilities. When we consider the limitations of the human abilities, we are faced with a real problem: we would like to take advantage of the limits of the human ability but we prefer to explore these limits so that risk of the loss of life is eliminated.

This brings the problem of simulating these human limits investigations on the ground, and to our second item, which is simulation and training.

SIMULATION AND TRAINING

A flight simulator is a mechanical and/or electronic device that is used to imitate an actual airplane. This is done in the manner shown

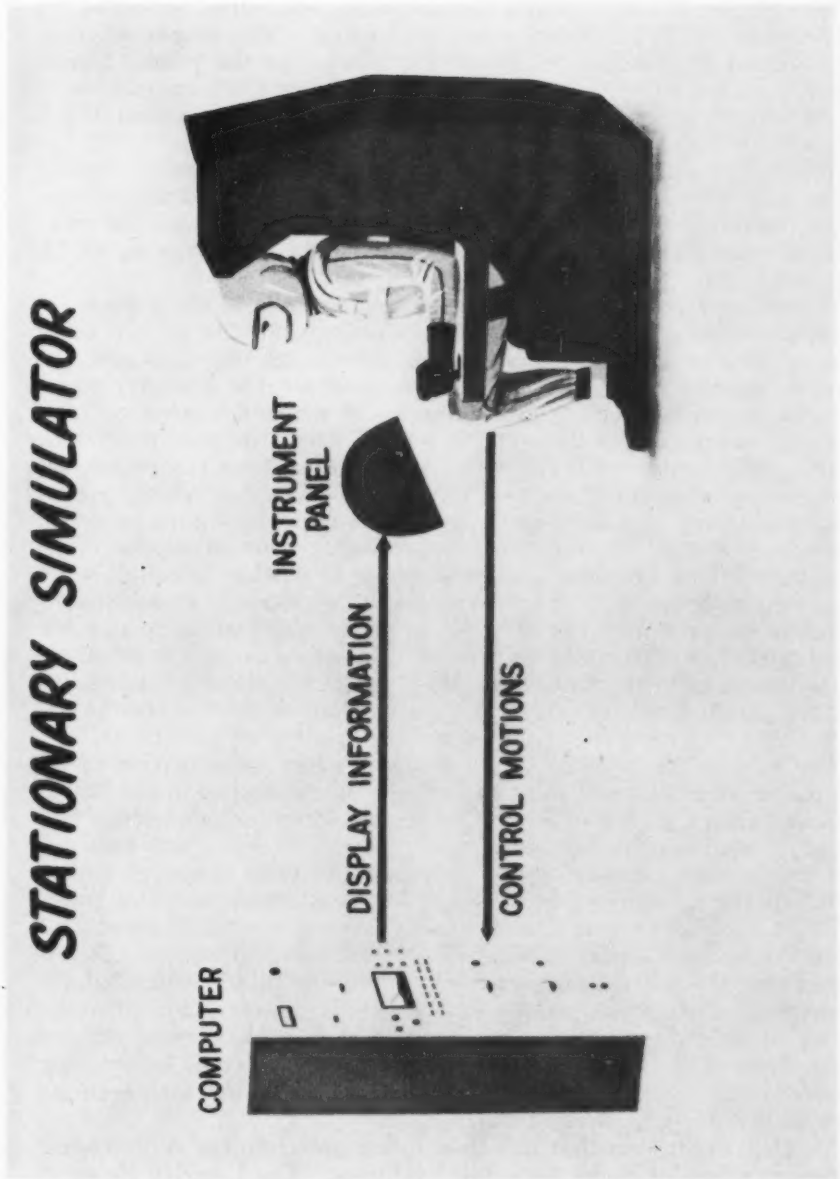

STATIONARY SIMULATOR
COMPUTER
DISPLAY INFORMATION
CONTROL MOTIONS
INSTRUMENT PANEL

FIGURE 199

on figure 199. We have here a pilot sitting in a cockpit mockup. This is called a stationary simulator because it does not move. The pilot has the usual controls and instruments on an instrument panel. When he moves the controls the electronic computer computes the response of the airplane that is being imitated. This response is then transmitted to the control panel and shown to the pilot. Consequently he can refer to these instruments and fly the airplane just as if he was flying a conventional airborne airplane in actual flight. He is flying blind by the normal instruments.

While flying the vehicle, the pilot has many other inputs that he feels, rather than just the visual ones of his instrument panel. He has the accelerations of the airplane, its rotations, the vibration, the noise. All of these either help or hinder him in the performance of his duties.

A necessary requirement in establishing the role of the pilot is the determination of his capabilities in the presence of the various flight stresses such as acceleration, vibration, noise, heat, etc. The point of interest in regard to each of these stresses is not the intensity which becomes injurious, but, rather, the points at which the stress causes a degradation in the pilot's performance of, first, precision tasks, and, second, crude tasks of low precision. Examples are the rocket airplane or booster vehicle such as X–15 or the Dynasoar vehicle. Here you have a very high level of rocket thrust which may put as much as perhaps 8 g. on the pilot during the launch portion of the flight. This level of acceleration is sufficiently high so that it could be expected to interfere with the pilot's ability to control. To adequately simulate this on the ground requires some modification to our stationary simulator for we can't draw conclusions about the effects of acceleration from the stationary simulator. We should check it under the actual acceleration. The manner that we do this is shown in figure 200 where we show our cockpit now mounted on a centrifuge.

The Flight Research Center has completed an investigation of the utilization of the human pilot as the primary controller in the launch of a multistage orbital glider. The investigation included centrifuge simulation on the NADC centrifuge at Johnsville, Pa. Both two- and four-stage launches were investigated over a wide range of vehicle stability and guidance conditions. Also evaluated was the pilot's ability to take over following failures of primary guidance and complete the mission using various types of backup guidance. It was found that the control task was well within the pilot's capabilities to withstand acceleration values considerably greater than presently under consideration. With proper support and 100-percent oxygen, there were only minor adverse physiological symptoms below 14 g. In most cases the pilot was able to complete the mission with accuracy limited primarily by his instrumentation.

Another flight area that has been investigated on the centrifuge is the entry phase of flight for orbital vehicles. The Langley Research Center performed an investigation, on the Johnsville centrifuge, in which the pilot's ability to control several different types of entry vehicles was evaluated. The vehicles ranged from the ballistic- or

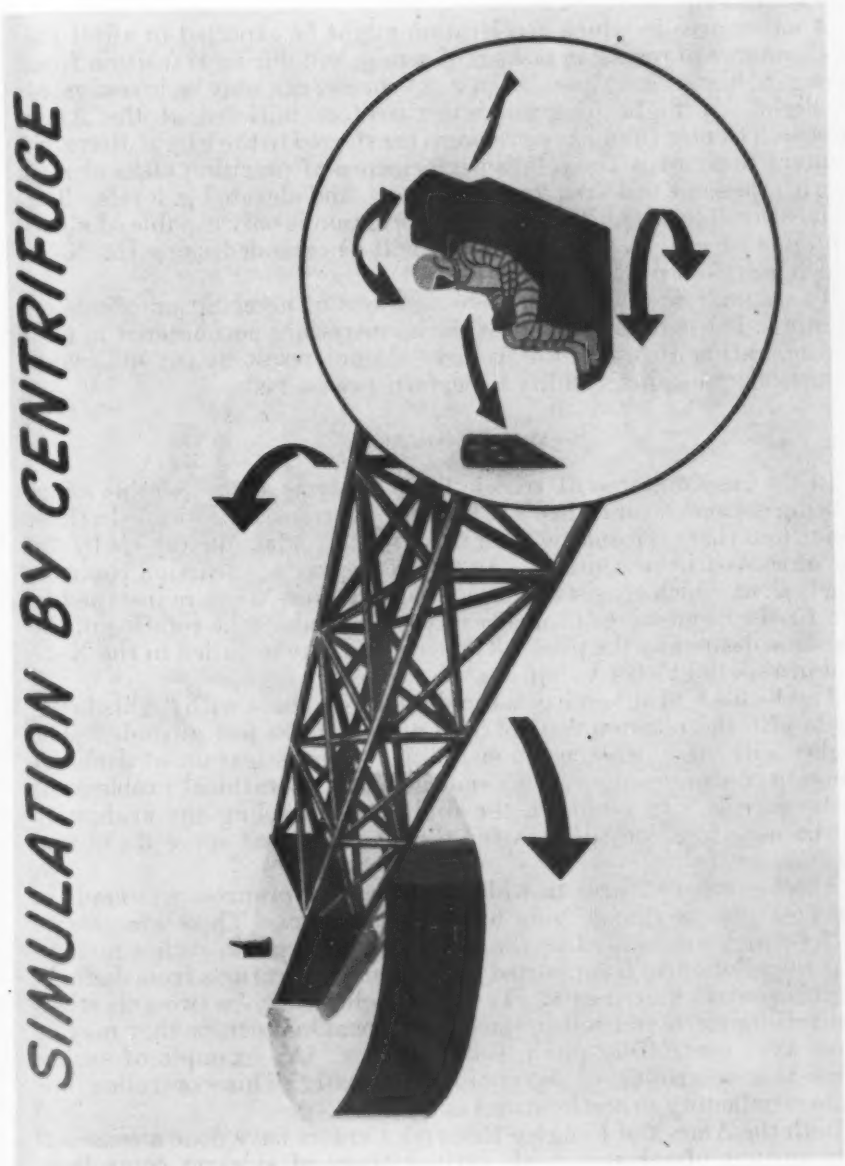


FIGURE 200

Mercury capsule-type to glider-type vehicles that fly like conventional airplanes. In all of these vehicles it was found that the pilot could control the vehicle satisfactorily with only minimum stability augmentation.

Another area in which acceleration might be expected to affect the performance of precision tasks is at zero g. and during transition from zero g. to higher g. values. Zero g., of course, can only be investigated in flight. A flight program was therefore initiated at the Ames Research Center (and has since been transferred to the Flight Research Center) to compare the pilot's performance of precision tasks at zero g. with the same tasks performed at one g. and elevated g. levels. The conventional jet airplane used in this program is only capable of about 1 minute of zero g., so the program will be extended using the X–15 which is capable of longer durations.

To summarize the various investigations of acceleration effects on piloting: It has been found that the accelerations encountered in normal operation of boost-glide vehicles do not result in any noticeable reduction in the pilot's ability to perform precise tasks.

FLIGHT CONTROLS

In the research area of vehicle flight controls a considerable effort is being expended for controls to be used at extreme altitudes. In these conditions there is insufficient air to materially affect the vehicle by the use of conventional controls. In this region we use reaction controls, one type of which consists of small rocket motors that are installed in the fuselage and wings in such a way as to produce the rotation of the airplane desired by the pilot. These controls are installed in the X–15 and in a special F–104A airplane.

The F–104A program has entered the flight phase with flights being made into the reaction control area above 85,000 feet altitude. The flights with this airplane are enabling the investigation of different reaction control configurations and the many operational problems of such controls. In addition, the flights are enabling the evaluation of the use of various devices for the simulation of space flight and attitude control.

Another research area in which considerable progress was made in the past year is that of side located controllers. These are control sticks which are located at the side of the cockpit in such a manner that the pilot's arm is supported to prevent accelerations from disturbing his control movements. These controllers may be two-axis sticks controlling pitch and roll in the conventional manner, or they may be three axis, controlling pitch, roll, and yaw. An example of such a three-axis controller is shown in figure 201. This controller was quite satisfactory to accelerations as high as 15 g.

Both the Ames and Langley Research Centers have done a considerable amount of research with various types of sidearm controllers. One investigation was carried out recently by the Ames Research Center in which a number of sidearm controllers, both two-axis and three-axis, were evaluated on the centrifuge. The designs used included the

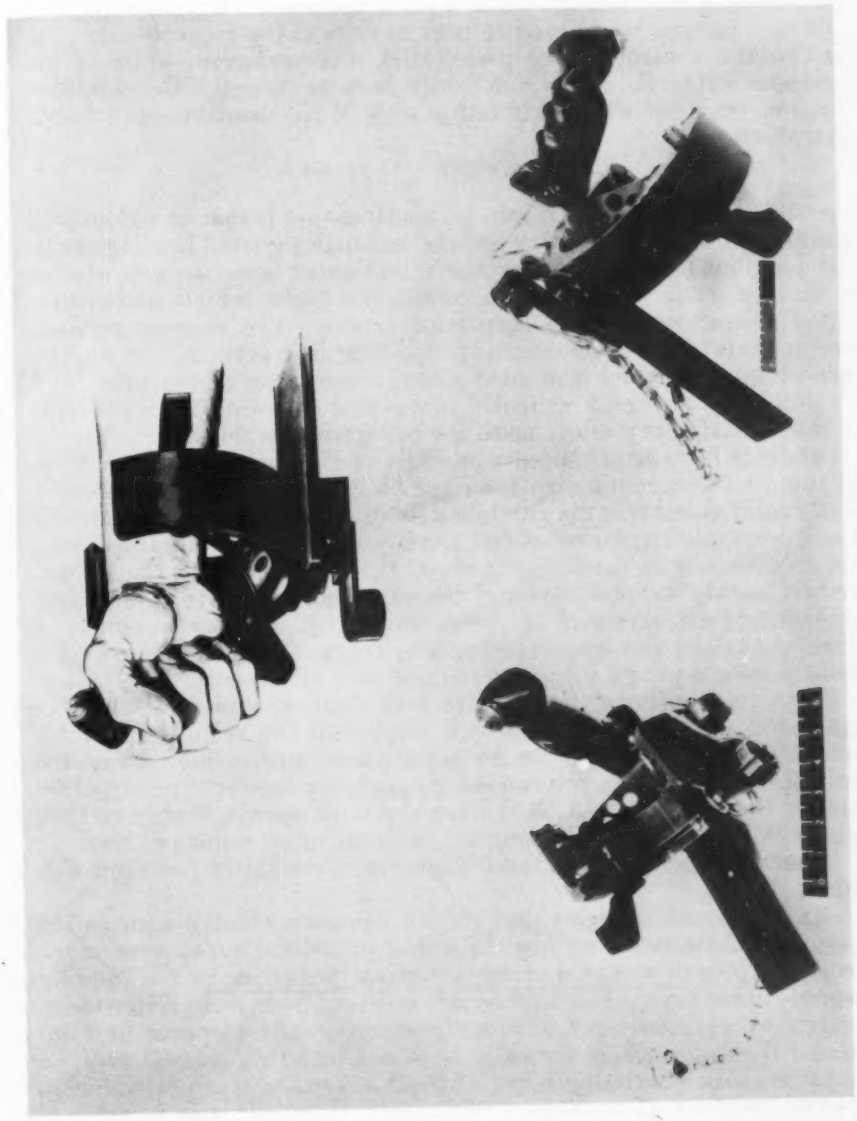


FIGURE 201

Flight Research Center controller described above, the Mercury controller, the X–15 controller, and a pencil stick developed at the Langley Research Center. These controllers were evaluated in centrifuge runs simulating the entry of an orbital glide vehicle of the Dynasoar type. The results of the tests indicated a pilot preference for controllers of the two-axis type when used to perform the entry control task. Of the two-axis controllers the pencil stick was preferred, while of the three-axis controllers the FRC stick was preferred. Considerable data was obtained which will aid greatly in the detail design of such controllers.

APPROACH AND LANDING

Another area of research into pilot utilization is that of navigating satellite vehicles during entry and descent to designated landing areas. The Langley Research Center has investigated some aspects of this by using a static simulator to simulate the flight vehicle and a simulated ground control or observation center. The various methods used included (*a*) ground control by voice instructions, (*b*) an airborne computer which provided visual indications to the pilot, and (*c*) automatic hovering control. It was found that all three methods produce satisfactory solutions to the navigation problem.

Landings have always been a problem and probably always will be. As the pilot brings his airplane close to the ground, he is nearing a pretty solid object that may do him a lot of damage. It may seem odd that hypersonic airplanes, as fast as they are, have landing problems, but it is because of the very nature of the configurations, that is, extremely highly swept wings and the very short span, that introduce problems of extreme rate of descent and high approach angle. In other words, the airplane in its landing approach is coming down extremely steep and at a very high rate of vertical velocity.

These are problems that we are investigating now in flight. In figure 202 are shown the approach angle and the vertical speed for various airplanes. These are no point shown on the line because the scale is nonlinear. As you can see, present-day fighter-type airplanes such as the F–102, 104–A, X–1 have approach speeds, that is vertical velocities in the approach, ranging from about 40 miles per hour up to about 80 miles per hour, and in general have fairly low approach angles.

The hypersonic vehicles that we are discussing today such as the X–15 and these two that are somewhat of orbital type, have much steeper approach angles and have vertical velocities in the landing approach that may get as high as 200 miles an hour,. In order to investigate these characteristics we used an F–104 airplane and increased the drag sufficiently to move it out into this general area, so that it is again simulating flight of the X–15 or these orbital vehicles. We then performed landings in these conditions. It was found possible to land with vertical velocities in the approach as high as 200 miles per hour. However, the pilots felt this was about the limit for this configuration, and that it was not the sort of a thing that a pilot could be sure of doing on his first attempt; that is, it would require additional practice.

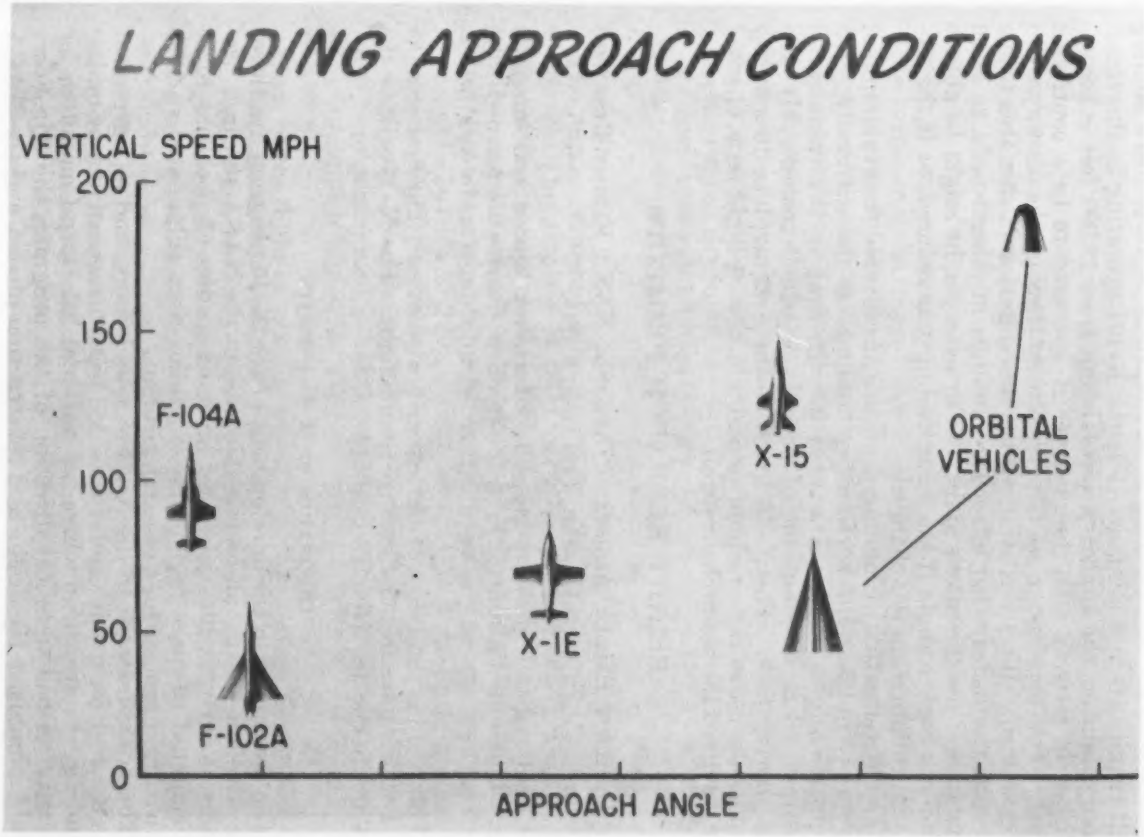

LANDING APPROACH CONDITIONS
VERTICAL SPEED MPH
200
150
100
50
0
F-104A
F-102A
X-1E
X-15
ORBITAL VEHICLES
APPROACH ANGLE

FIGURE 202

The conventional transport airplane descends from an altitude of about 18,000 feet. The descent time will be about 30 minutes to the time it starts its landing approach. For an airplane such as the F–102 or the F–104, operating in service, from 18,000 feet to a landing will require about 5 minutes. For the F–104 operating in this simulated condition, the approach and landing from 18,000 feet is accomplished in seconds. To the observer it appeared to be a controlled crash. One expected to see the airplane go through the runway when it contacted. We are continuing the investigation in this area to determine the factors that affect the landing; in other words, to learn how to best use the pilot's ability. For example, he might be able to land at a higher angle if his wing loading was reduced, or if the airplane configuration was changed.

The investigation of landing problems has covered the evaluation of several techniques for performing landings at the extremely steep approach angles which characterize low lift-drag ratio airplanes and has resulted in development of procedures which considerably ease the piloting task. The X–15 has been the first airplane to actually require the use of these techniques and it has, in its flight tests, checked the results of the research very well.

FLIGHT RESEARCH PROJECTS

By DeElroy Beeler, Assistant Director, NASA Flight Research Center, Edwards, Calif.

Flight research projects take the laboratory lessons and integrate them into actual aircraft; first, to see if the lessons we learned were correct, and second, to see if there is anything overlooked in our laboratory studies.

The X–15 is the latest of our research airplanes. The first was the X–1 which gave us our first supersonic flight. The X–15 will be the first one to take us to the fringes of space.

INITIATION OF X–15 PROJECT

The milestones in the development of the X–15 program are these: The airplane became an identifiable item in the NASA research programs as early as 1952 when we initiated studies of problems to be encountered in space flight. These studies were culminated in 1954 with a firm proposal for a research airplane.

This was presented to the Air Force and Navy, and an agreement was reached for a joint endeavor. A formal memorandum of understanding was drawn up where the National Advisory Committee for Aeronautics had technical direction of the program, the Air Force would administer the design and construction phases, and the NACA had the responsibility for the flight research program.

North American, after a design competition, was given a contract to go ahead with three airplanes in December of 1955. In October of 1958, the first X–15 airplane was rolled out and delivered for flight tests. Since then there have been numerous ground tests of all the various accessories and power systems within the airplane.

The appearance of the X–15 is in a sense relatively conventional. Its difference really lies in the manner in which it is constructed, and the internal arrangements. The skins are of Inconel X, which is a nickel alloy rather than aluminum alloy usually used in aircraft construction.

X–15 INTERNAL ARRANGEMENT

The internal arrangement approaches that somewhat of an ICBM missile. The major portion of the fuselage is taken up by the fuel tank, and the liquid oxygen, and the associated equipment running back to the rocket engine.

A large area is taken up by instrumentation. In a sense the heart of the airplane is the compartment which holds the small turbine units that drive generators and hydraulic pumps that supply electrical energy for the airplane systems, as well as the hydraulic power required to operate the control surfaces.

The landing gear of the airplane is somewhat unusual. It has a conventional nose gear shown in the retracted position, and then the main gear, which, rather than being wheels are skids that extend from the rear of the fuselage.

The fuel tanks actually are integral tanks which are also part of the fuselage structure.

X–15 PERFORMANCE

The maximum speed of the airplane is approximately 4,000 miles an hour. The airplane is still increasing its speed when the rocket propellants are exhausted. The airplane has been designed for altitudes up to 250,000 feet or about 50 miles. The plane is built to withstand temperatures up to 1,200° F.—that is the temperature that is expected to be encountered on a reentry maneuver from an altitude of 50 miles. Higher altitudes are within the performance capability of the airplane. However, one of the purposes of the flight research program is to determine the heating and flight control problems to determine how much higher an altitude can be attained with guaranteed safe return.

Part of the flight envelope is available in terms of space flight where aerodynamic forces would be negligible. Aerodynamic problems are involved in another part of the flight envelope. In the space area, investigation of reaction controls will be possible. The pilot will be subjected to weightlessness and be in what one might call a space equivalent condition.

To give an indication of the performance increase that the airplane represents, it should be noted that the lower speeds have been well explored by present-day military jet fighters. Next, the envelope covered by the X–2 airplane's speeds is 2,094 miles an hour and altitudes of 126,200 feet.

TYPICAL X–15 FLIGHT

Here is a description of a typical mission. The airplane operates over an instrumented radar telemetering range extending essentially

from Wendover, Utah, to Edwards Air Force Base. Stations are located at Ely, Nev., and Beatty, Nev. This route provides numerous dry lakes which would be available for landing areas in the event of an emergency (fig. 203).

Edwards has a very large dry lake and this is the prime reason for conducting the operations at that point. In addition, there are lakes disclosed along the route that will cover just about every emergency.

At Wendover there are the Bonneville Salt Flats, and these will provide a good emergency area if for some reason after launch the rocket engine does not start.

In the rocket system we do everything prior to launch but actually open the main propellent valves. The turbine pump will be operating; in fact, the igniter will be on prior to launching the airplane. This will reduce the possibility of having an abort flight and an emergency landing.

This particular mission is called an altitude mission, where the objective is high altitude rather than the high speed. The pilot will undergo high longitudinal accelerations forcing him back in his seat, and this will increase from the time the rocket engine is fired. As the airplane lightens, it will go up to the order of 5 G's.

At that point, fuel will be expended. However, the aircraft will coast upward to a higher altitude and it is in this area that the pilot will experience a weightless condition and will operate the space controls or reaction controls to properly orient the airplane in order to make his reentry.

The reentry will cause the airplane to heat up, and the pilot will have to exercise very precise control in order to avoid overheating or overstressing the airplane.

At the completion of his reentry he will be about 80,000 feet and perhaps 3,000 miles an hour, and his problem then is to navigate to Edwards and land the airplane.

He will have radar and telemetry monitoring all along the flight path.

FLIGHT RESEARCH PLANS

The exploratory flight program, to reach the designed missions of the airplane, will be conducted by the NASA Flight Research Center. The airplane will actually be flown by Air Force, Navy, and NASA pilots. The program will be conducted in a step-by-step manner, not necessarily in given increments of speed but in increments of knowledge, extrapolating our experience to the next advance.

There has been a lot of work on the X–15. There have been over 4,000 hours of wind-tunnel testing, and this is actually many more hours than the airplane will ever fly.

Simulator and centrifuge studies have been conducted in which the pilots have flown the profile of the X–15 airplane in a very satisfactory manner. Mapping of the expected temperatures on the airplane, quoting temperatures up to 1,200°, which is the safe working range for the Inconel X, have been completed (fig. 204).

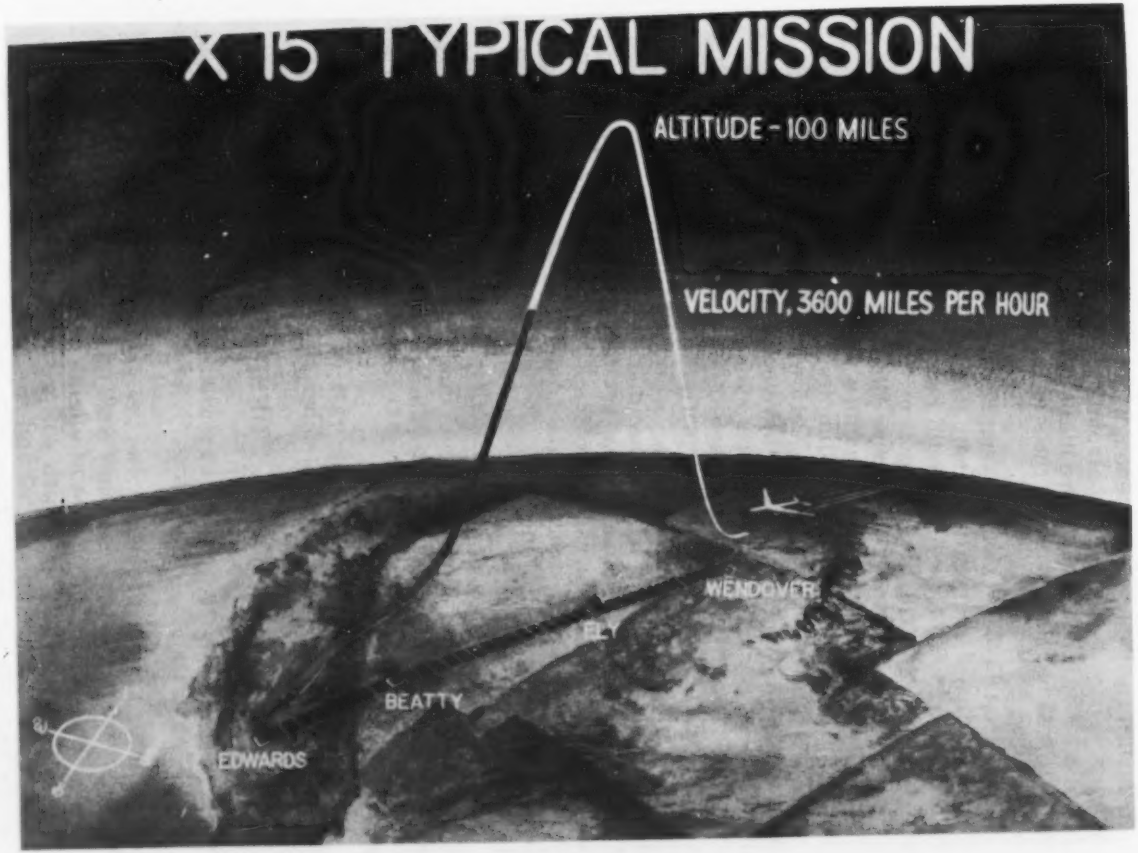

X 15 TYPICAL MISSION
ALTITUDE - 100 MILES
VELOCITY, 3600 MILES PER HOUR
WENDOVER
BEATTY
EDWARDS

FIGURE 203

The areas at the nose and wing leading edges are exposed directly to the wind as you fly, and get very hot. There is also a pullup reentry case where certain parts are cooler on the back side or shadow areas of the structure than are the exposed areas.

This information is good enough for design purposes when we design a safety margin in the airplane, but because we do not know the actual flow conditions in free flight and the exact manner in which the heat will be transferred to the structure we have certain areas of uncertainty.

On figure 205 the structural temperature is plotted against speed with a predicted temperature line. But at any given speed we have an area of uncertainty which would be off as much as 400°. If this part is a critical structural component, we must approach our flight testing in such a manner to narrow this band of uncertainty down as our speeds increase. In this manner we get the maximum utilization of the airplane without exceeding its limits.

The first powered flight of the X–15 was made in September 1959, and since then 16 powered flights have been made by the two operating X–15 airplanes. Three reports summarizing the results of the early flights have been published and others are in preparation. The second airplane is being equipped with the XLR–99 engine which is the maximum-performance engine. In early November 1959, one of the airplanes suffered a landing accident during contractor demonstration flights which damaged the fuselage. The airplane was repaired and in flight status by the middle of December 1959. The third aircraft suffered structural damage during ground running of the XLR–99 engine in June 1960. Repair of this aircraft has been started.

The No. 1 aircraft was turned over to the Government on February 9, 1960, and has been flown to a maximum speed of 2,111 miles per hour at an altitude of 67,550 feet by an NASA pilot on May 12, 1960, and to a maximum altitude of 107,000 feet by an Air Force pilot on May 19, 1960.

It is expected that the second aircraft will be flown with the maximum-performance engine by September 1960.

MISSILE DESIGN

By Milton B. Ames, Jr., Deputy Director, Advanced Research Programs, NASA

The major missile problem areas are engine performance, control and guidance, structural efficiency and integrity, aerodynamic heating, and materials. In the area of engine performance, modern missiles require rocket engines which will give the highest possible performance for each pound of fuel and engine weight.

As an example of some of the difficulties here, modern ballistic missile powerplants consume 100 gallons of fuel per second.

The second item is the area of control and guidance. Modern missiles require fully automatic control systems, and these control

X-15 AERODYNAMIC HEATING
1100°F TO 1200°F
1000°F TO 1100°F
800°F TO 1000°F
BELOW 800°F

FIGURE 204

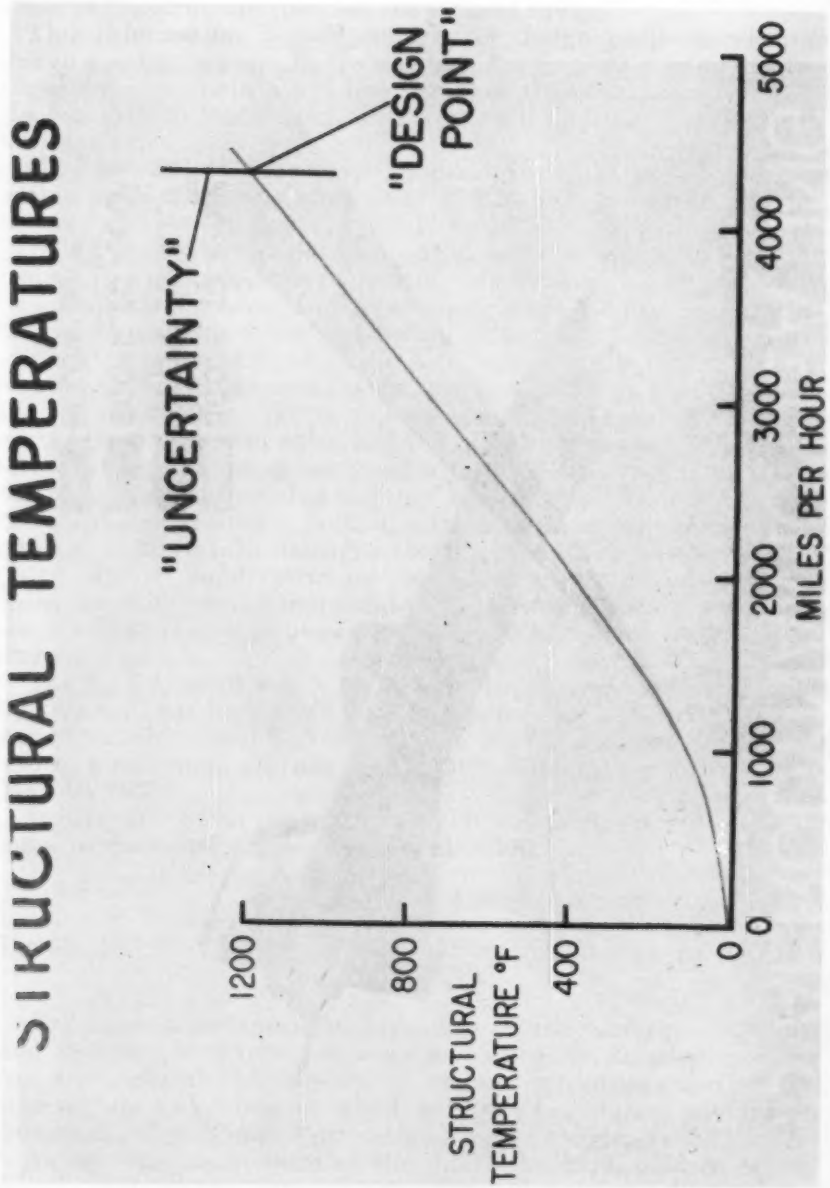

STRUCTURAL TEMPERATURES
"UNCERTAINTY"
"DESIGN POINT"
1200
800
400
0
STRUCTURAL TEMPERATURE °F
0
1000
2000
3000
4000
5000
MILES PER HOUR

FIGURE 205

systems receive their instructions or signals from elaborate electronic guidance equipment. When we couple these parts of the weapons system with the rest of the vehicle, we end up with a complicated array of devices which are required to perform with extreme precision.

Structural efficiency and integrity requires the lowest possible structural weight which will withstand the loads, the temperatures, and the vibrations which the missile will experience without structural failure.

Aerodynamic heating and materials are related and they in turn relate back to the requirement of having the lowest possible structural weight.

In the area of aerodynamic heating we are searching for means by which we may reduce the heat input into the missile. And in the area of materials, we are striving to find better materials and better methods for withstanding the temperatures which will be encountered by the missile.

NASA CONTRIBUTIONS

NASA contributes to the solution of missile problems through general research programs. Our objective at NASA is to develop as much of the basic engineering technology as we are able to provide in order to contribute to the design and development of advanced missile types. The results of NASA research investigations are made available to the military services and to all of the designers of missiles in this country. Our results have contributed importantly to the advancement of the Nation's missile program.

The second important way in which NASA talent is brought to bear on missile problems is by investigations of specific missiles. Here the NASA scientist brings to bear his skill and experience from the general research programs to improve the performance of a specific missile or to solve a particularly difficult problem which a specific missile has encountered.

NASA STUDIES OF SPECIFIC MISSILES

In the last several years NASA research centers have tackled over 100 problems of specific missiles. The names of some of these missiles on which we have worked are as follows:

Ground to air:
- Bomarc (Air Force)
- Talos (Navy)
- Hawk (Army)
- Nike-Hercules (Army)
- Nike-Zeus (Army)

Air to air:
- Sidewinder (Navy)
- Sparrow (Navy)
- Falcon (Air Force)
- Advanced Falcon (Air Force)

Ground to ground (winged):
- Snark (Air Force)
- Matador (Air Force)
- Navaho (Air Force)
- Regulus II (Navy)

Air to ground:
- Rascal (Air Force)
- Bullpup (Navy)
- Corvus (Navy)
- Hound Dog (Air Force)

Ballistic:
- Redstone (Army)
- Thor (Air Force)
- Jupiter (Army)
- Atlas (Air Force)
- Titan (Air Force)
- Polaris (Navy)
- Minuteman (Air Force)
- Pershing (Army)

CONTROL PROBLEMS

The control effectiveness of a winged interceptor missile varies with increasing airspeed as indicated by this black line. At the highest speed there is little control effectiveness, which means that the missile has little or no maneuverability at this speed. As a result of wind tunnel and rocket-powered model studies at our Wallops Island station, this control effectiveness or maneuverability was improved. We now have as much control effectiveness at high speeds as we had previously at 1,500 miles per hour.

Moreover, the control effectiveness has been increased at all speeds above 1,000 miles per hour. This problem of loss of control effectiveness of hinge controls with speed has been with us for a long time and has been the subject of a number of general research investigations at our research centers.

One arrangement discovered in these investigations is being incorporated in the design of a new short-range ballistic missile (fig. 206). If we compare this new control with the size of a conventional control surface to give equal lift or control effectiveness at 7,000 miles per hour, we see a number of interesting things. First, since this is a short-range ballistic missile, one of the requirements is that it be highly mobile. We have a shorter span, which helps. The stubby surfaces are also more rugged. In addition, this larger more conventional surface would be heavier structurally.

This new control arrangement was discovered during a general research investigation, and controls of this type, have also been applied to the X–15.

WIND VIBRATION PROBLEMS

Wind vibration is another problem.

First consider the missile when it is standing on the launching pad. It has been known for some time that tall smokestacks are susceptible to damage in high winds. In view of the extremely light structure of ballistic missiles, it was suspected that perhaps a missile on the launching pad could experience damage by wind vibration.

So a model of a ballistic missile was installed in one of our wind tunnels and tested. It was found as suspected that the lightweight structure of the missile was susceptible to wind damage due to vibrations when standing on the launching pad. If we consider a cross-section through the missile near the top; that is, this black disk on figure 207; and the wind is passing across the missile, we find there is an alternate shedding of what we call vortices. The little swirls of air come off on the opposite sides alternately.

This alternate shedding of vortices can and in many cases will set up a vibration of the missile. One way of handling this is to put small strips at the top to break up the manner in which the vortices are shed. By application of such a device to the missile we find we can reduce the loads to about half of their original magnitude.

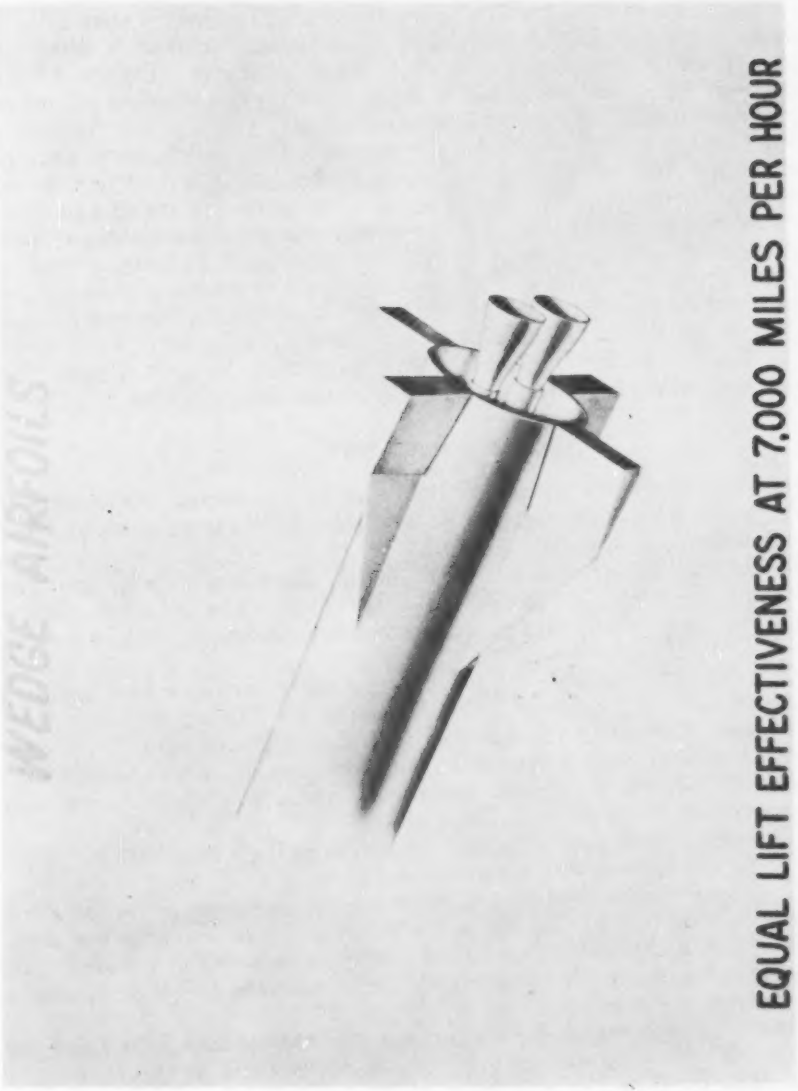

WEDGE AIRFOILS
EQUAL LIFT EFFECTIVENESS AT 7,000 MILES PER HOUR

FIGURE 206

LAUNCH AND STAGE SEPARATION PROBLEMS

Another area in which we encounter quite a few difficulties with ballistic missiles is in the launching and stage separation phases of flight. In this area we find that our wind tunnels can give us a good deal of information to help. Now most of the problems in this area are unanticipated for two primary reason. The first is that a large number of variables are involved. The second reason is that the airflow is quite disturbed during these stages of flight. Figure 208 is a picture of what one would see looking through the window of one of our wind tunnels during a stage separation test.

This test was run at supersonic speeds. The shock wave pattern and the air flow in this region shows that a great deal of flow interference is involved. By investigations of this type we are able to simulate the various conditions of launching and stage separation and provide detailed measurements on the loading, the local heating and on the stability. This helps in the design of the structure and in the design of the control system. This type of investigation has now become standard practice in the development of ballistic missiles.

We have run investigations of this nature on Polaris, Titan, Pershing, and others including NASA space launching vehicles.

BASE HEATING

Base heating is a problem that was demonstrated quite vividly when we made our first attempts to launch ballistic missiles at Cape Canaveral.

In one instance after a beautiful take off there was a flash, an explosion and fire and the missile was destroyed. The military service brought this problem to one of our research centers. What we call base heating was suspected.

A model of the missile with operating rocket engines was installed in one of our wind tunnels. We found the air flowing on the outside of the missile at about the speed of sound, was drawn up into the base cavity, and as it passed over the hot rocket nozzles, it was heated. In addition fuel-rich mixtures, exhausted from a turbine, were also drawn up into this cavity and heated.

Temperatures measured in our tests were as high as 1,400° F. This was all that was needed to cause an explosion.

As a result of these tests, a recommendation was made that the missile be modified so that cool air was drawn in to scavenge the area, and some additional cooling to the rocket nozzles was provided. In addition the exhaust pipe was lengthened so that the fuel-rich mixtures were carried downstream.

These changes resulted in reducing the temperatures in the base region. There were also two favorable byproducts of the investigation. The drag or the resistance of this missile was reduced by the

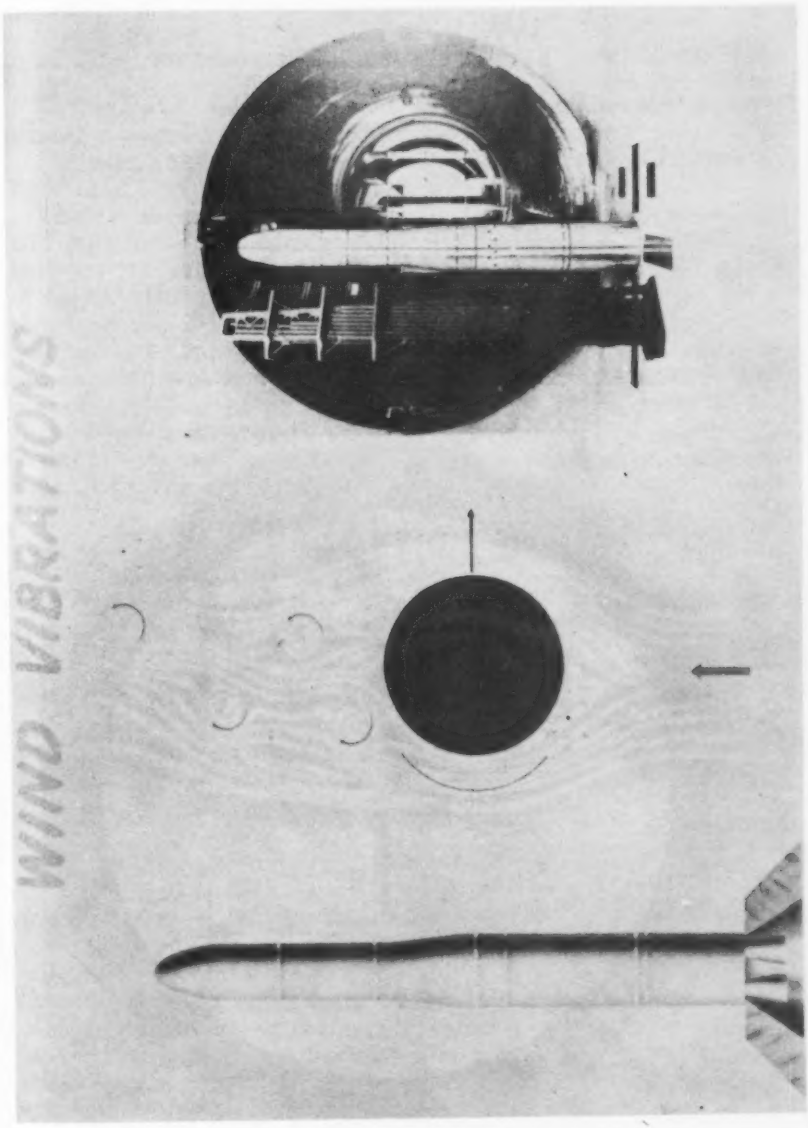


FIGURE 207

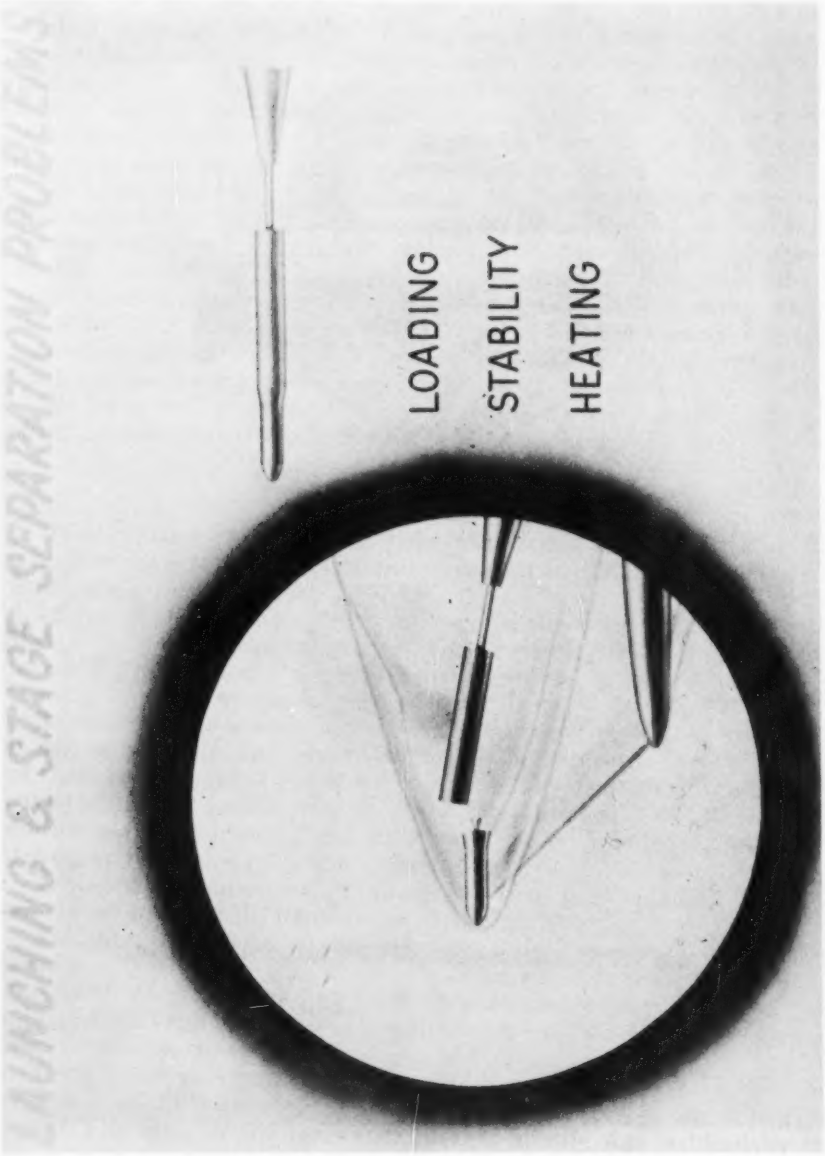

LAUNCHING & STAGE SEPARATION PROBLEMS
LOADING
STABILITY
HEATING

FIGURE 208

modified arrangement. Also the rocket nozzles swivel for control, and in this instance the forces required to move these nozzles were very large and erratic. In the later configuration the controlling moments on the nozzles have been reduced and now vary much more regularly than they did in the earlier arrangement.

INSTABILITY OF BALLISTIC MISSILE NOSE CONES

The dynamic stability of reentry models or bodies such as a ballistic missile nose cone is still another problem area.

Ballistic missile nose cones enter the atmosphere at velocities between 12,000 and 15,000 miles per hour.

These nose cones decelerate rapidly as they penetrate the atmosphere and experience increasing atmospheric density, and just before impact, they are moving at speeds considerably less than the initial velocity of entry. During this entry they must not burn up, but they must also be stable. If they are not stable, they may oscillate in such a manner as to burn unprotected parts of the nose cone and we could not expect them to reach the target with any reasonable degree of accuracy. This stability problem has been investigated throughout the entire speed range in both general research and specific development programs at our centers using the various pieces of research equipment which we have.

FLIGHT CHARACTERISTICS OF MISSILES

By H. Julian Allen, Chief, High-Speed Research Division, NASA Ames Research Center, Moffett Field, Calif.

There are covered in this section some of the problems that are associated with the entry down through the atmosphere of ballistic missiles, in a very fundamental way, some of the solutions of these problems, and how these solutions have been employed in some of our current vehicles.

BALLISTIC MISSILE TRAJECTORIES

As we know, when you throw a ball you throw it farther if you throw it faster. But in addition to that you will throw it farther for a given speed, if you throw it at a particular angle, which happens to be about 45 degrees, when we are essentially in short ranges.

Now we are interested in these optimum angles of attack because this requires the least energy input for a given range. When you come to ballistic missiles the same thing is true. The speed, of course, is considerably greater because you are talking about thousands of miles instead of hundreds of feet, but it is still true that there is an optimum angle to throw this vehicle at, for which you will have to provide the least velocity for the given range.

We are attracted to use such optimum paths, or trajectories, because in that way we don't have to supply any more thrust for any longer period than is absolutely necessary, and as a result it keeps the missile smaller.

On figure 209 is shown what these optimum trajectories look like.

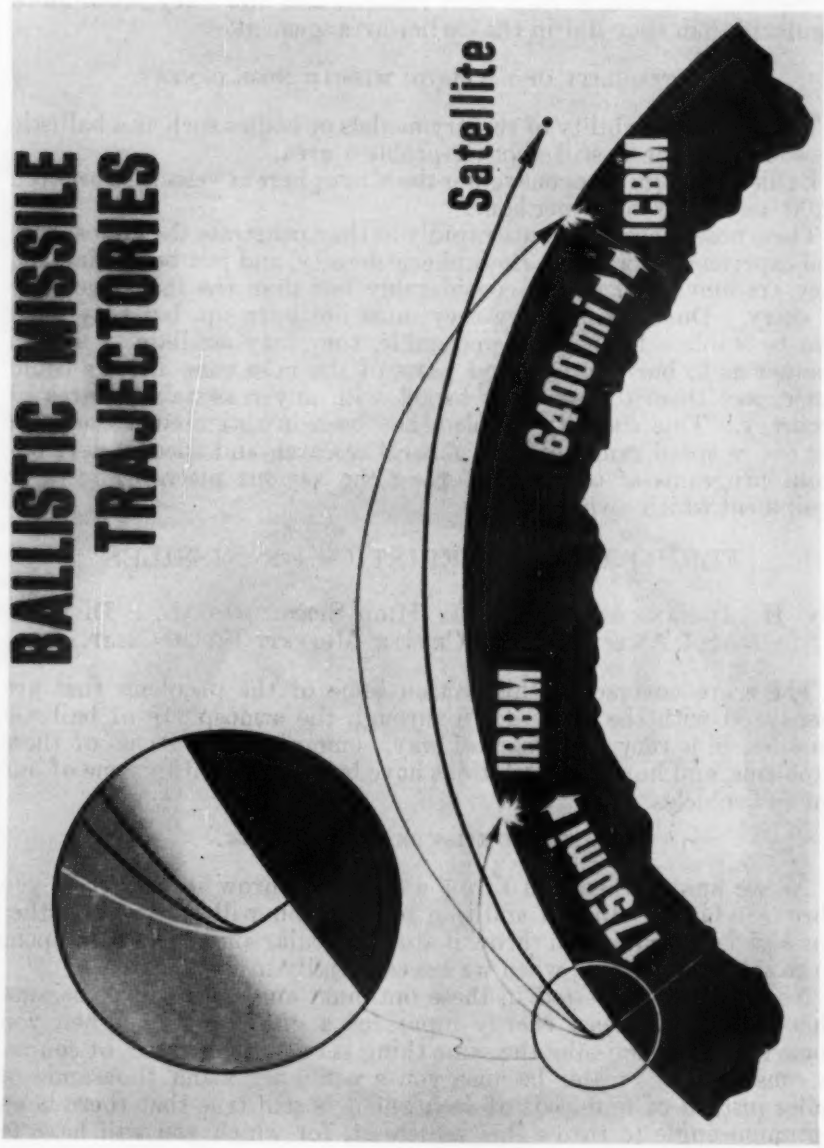

BALLISTIC MISSILE TRAJECTORIES
Satellite
ICBM
6400 mi
IRBM
1750 mi

FIGURE 209

First the vehicle is boosted vertically. This is done principally to get the vehicle out of the atmosphere as soon as possible so that its aerodynamic drag and the aerodynamic heating that is associated with it don't become active during this phase of the flight. Then the guidance system gives the vehicle the command to turn such that at the end of the powered flight it is flying the beginning of the optimum trajectory.

The interesting point about this is that the optimum trajectory for the IRBM, the optimum angle, is a steeper angle, than it is for an ICBM, and in turn the angle goes to zero as you go to satellite speeds because you are just flying tangentially with respect to the earth. This has an important bearing on some of the problems that have come up.

MAXIMUM DECELERATION DURING ENTRY

Let us consider the motion or the retarding forces that are experienced by a ballistic missile. The retarding force as plotted in figure 210 as a function of range is seen to rise to a maximum value at around 5,000 miles. It amounts to a little less than 60 g.'s deceleration. The reason that it increases at first is because the velocity is increasing. When it comes back into the atmosphere, the velocity is very much higher since the product of the square of velocity times the density, the force is naturally increasing with increasing range.

The reason why it decreases on the other side, however, is due to the falling. Even though the speed is increased the angle is becoming sufficiently flat that the rate of increase of density with time offsets this effect, so that the vehicle experiences lower loads. In other words, the forces act for a longer period of time. You can see here we get up to about 60 g.'s in this range. When we get to satellite speed we have to go through a period of close to 8 to 10 g.'s.

The interesting point here though is this: The shape of this thing or its weight has not been discussed because it has no bearing on the problem. These forces are experienced irrespective of what the shape of the vehicle is or its weight. The only way that they will not be reached is if it hits the ground before this maximum value is reached. Otherwise, if it is reached within the atmosphere, it is independent of the shape. Therefore, there is no indication about what a vehicle should look like, looking just at the deceleration, and it is not a particularly difficult problem to provide a structure which will stand up under this sort of a load.

STATIC STABILITY

Stability is a field in which the shape has considerable effect. First, there is the static stability. As the vehicle comes in from outside the atmosphere it may be faced in another direction than the way in which it is traveling.

We say it is statically stable if, when it enters into the atmosphere and begins to feel the aerodynamic force, the aerodynamic force tends to turn the nose first in attitude. It is statically unstable if it wants to turn around, and obviously we are interested in having a statically

MAXIMUM DECELERATION DURING ENTRY
IRBM
ICBM
SATELLITE
60
40
20
DECELERATION g's
0
5,000
10,000
15,00
RANGE, MILES

FIGURE 210

stable vehicle because otherwise you will get into additional problems.

So the question is how does this vary with shape? Figure 211 will demonstrate some characteristics about the effects of shape on this. The center of mass of the vehicle will lie across it at or near the center of volume of the body because if you just distribute the parts around in there uniformly you would be at the center of volume.

Let's take the case of a very blunt shape. The forces which act on it act perpendicular to the surface, so they tend to intersect at a point behind the missile, in other words, behind the center of mass. Consequently, if on the blunt vehicle when it is in this downward direction the top force increases, the bottom force decreases, and the result is that there is a net moment to right it. This kind of a shape tends automatically to be stable, to be statically stable. On the other hand, if we go too far with this business it is possible, for example, to have these lines intersect on the center of mass, in which case it has neutral stability. It has no tendency to return at all. Long, slender shapes tend to be unstable in this respect, so, consequently, from the static stability point of view we favor very blunt shapes.

Another concept of stability is what is termed "dynamic stability." If we take a statically stable vehicle, that is, one that wants to be turned to zero—of course it will overswing like a pendulum. It goes over to the other side and then it comes back, and so on, and if in these ensuing swings it damps out, we say it is dynamically stable. If on the other hand it swings further and further it will eventually tumble.

We found in considering dynamic stability that when a vehicle first enters the atmosphere the fact that the density is increasing very rapidly and the vehicle is still moving fast makes practically any vehicle stable dynamically. But near the lower part of the trajectory, near the speed of sound, for example, we have found that in that range the dynamic stability is an important item. And we have to try to lick this problem. We have found that one of the most serious shape factors as far as dynamic stability is concerned is if the vehicle is too blunt in front, or if the face is flat, the vehicle tends to be dynamically unstable through a rather large range. However, if we go even to a little more conical shape than that, we find this immediately is made satisfactory and shapes like this are quite satisfactory.

So far what we have seen is that as far as the loading is concerned the shape is of no importance. As far as the stability is concerned we want relatively blunt shapes but we don't want them too flat faced. This gives us plenty of latitude as far as the shape is concerned. But the thing that determines really the final shape is the aerodynamic heating, because this is the problem which is the most serious for these vehicles. These things are going to become meteors and like most meteors they burn up on the way down because the energy that is available far exceeds the heat that would be required to vaporize them.

So we have to be very careful that we don't put a large fraction of this energy into the vehicle.

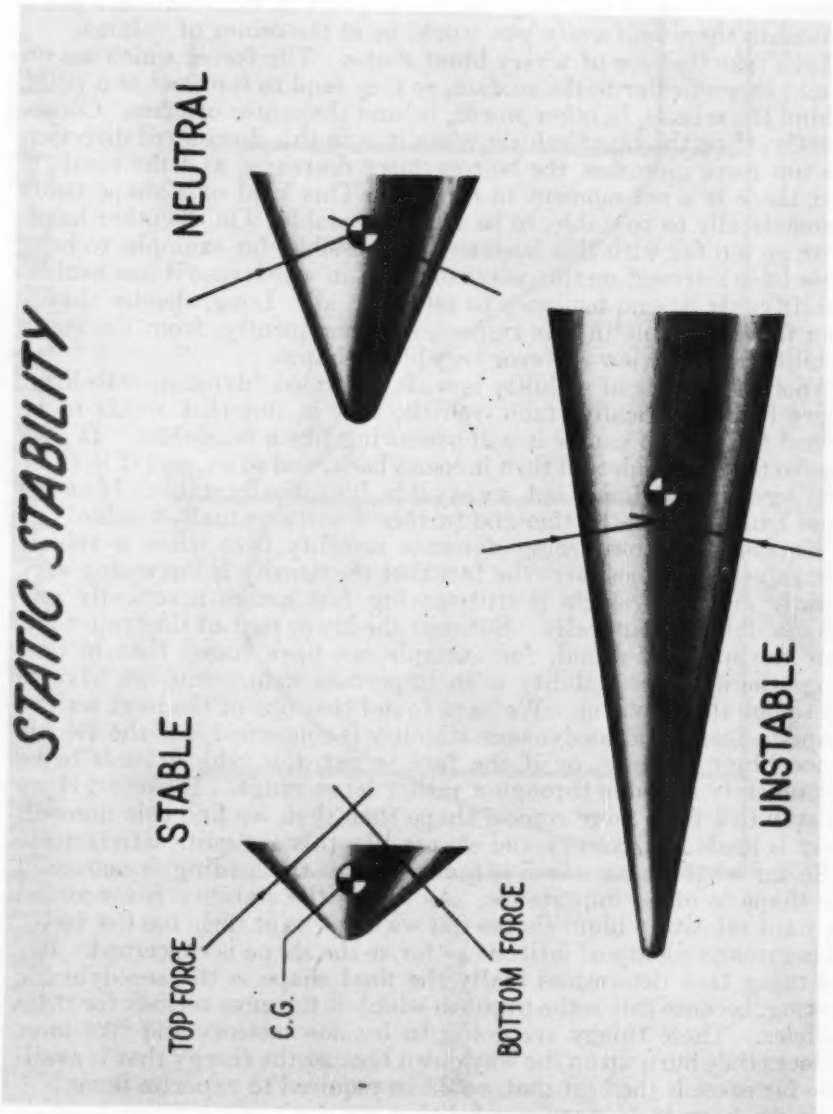

STATIC STABILITY
NEUTRAL
STABLE
UNSTABLE
TOP FORCE
C.G.
BOTTOM FORCE

FIGURE 211

FLOW ABOUT SLENDER AND BLUNT BODIES

The way in which heat enters the vehicle is through the shearing forces that go on in the air that is close to the surface. We call this little thin layer around the surface the boundary layer, and it is the work done in shearing these layers that promotes these high temperatures in the air which in turn can be transmitted to the vehicle. So the question is how do you get around this thing?

There are two aspects of this problem. One is a consideration of the total amount of heat that goes into the vehicle, because this determines the amount of material which has to act as coolant. On the other hand, we are also interested in another phase of it. That is we are also interested in what is the maximum time rate of heat input, how rapidly does the heat go into it, because this in turn determines not so much the amount of the material but rather the kind of material.

In figure 212 is shown the amount of the heat in millions of British thermal units, as a function of the cone angle of simple round nose cones.

A British thermal unit is enough heat to raise 1 pound of water 1° F. A better way to look at it is this is the amount of heat it takes per pound to bring copper up to melting. So what this means is that we have to at least have a 40° cone angle. Otherwise even at 40° cone angle the thing will melt away.

If it was made of solid copper it can't even bring itself down much less protect a payload so we have to get out to a cone angle of about 100° in order to bring this down to a satisfactory value, to get down to the point where the heat sink is of less weight than the payload. Otherwise you have to provide the coolant to keep the coolant cool. That is what it amounts to, and that is a rather poor and uneconomical way to handle this business.

To show why this state of affairs exists, we refer to the two pictures in figure 213. One, we use what we call shadows. They are taken of models in flight and they show the main disturbances that exist in the airstream. Along the edge is seen the boundary layer as it develops. It is probably the principal disturbance in the field. Other waves are strong but still not as prominent as the boundary layer. On a blunt body you can't even see the evidence of the boundary layer. It is a minor disturbance compared to the very, very intense shock wave.

What that means is that with the sharp nose the principal shearing that is going on is right next to the body so that the body takes in this heat. In the other more blunt case the shearing that is going on is going on out in the atmosphere, in the wave in front of it. Consequently since practically all of the energy the vehicle has when it comes in has to be converted to heat, by going to a blunt shape you give the heat to the atmosphere so you don't have to take it on yourself. With the sharp nose, something like 35 percent of the total amount of energy will go into the body. With a blunt nose, only about a half of 1 percent goes into the body, so that is the way you solve this kind of a problem.

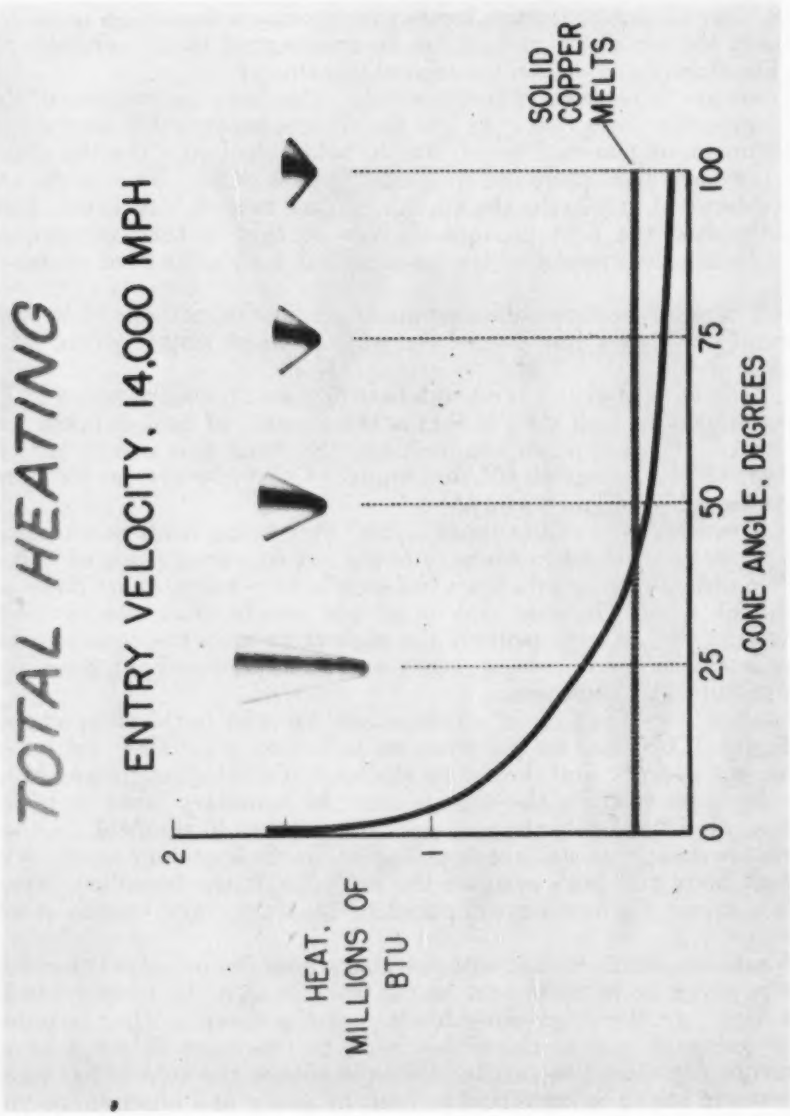

TOTAL HEATING
ENTRY VELOCITY, 14,000 MPH
HEAT, MILLIONS OF BTU
2
1
0
25
50
75
100
CONE ANGLE, DEGREES
SOLID COPPER MELTS

FIGURE 212

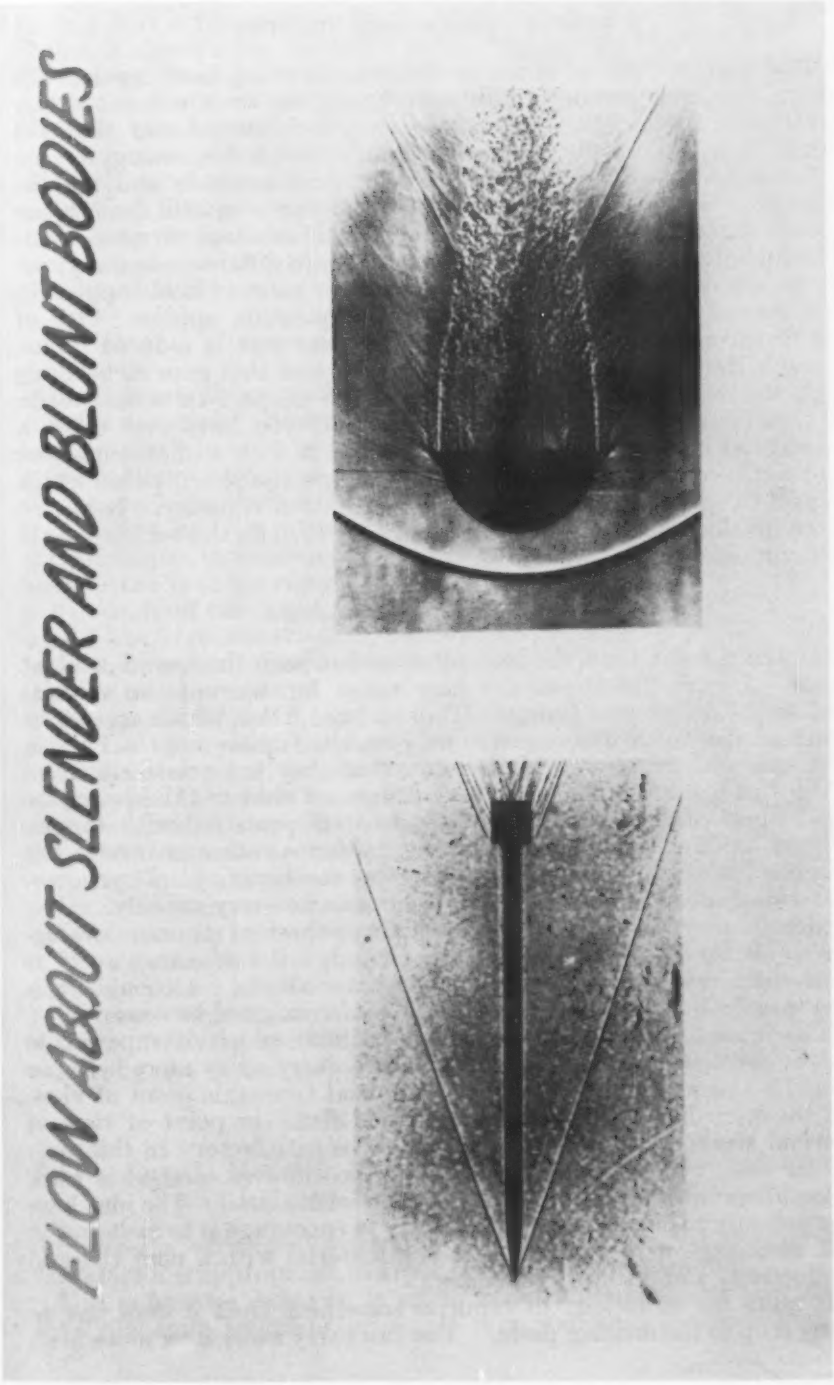


FIGURE 213

RATE OF AERODYNAMIC HEATING

The next feature to cover is the time rate of heat input. The reason this is important is that these heat rates are always at a very great rate, so that the outside gets very hot much faster than the inside does because the heat simply can't run in fast enough.

Whenever you do this kind of thing, heat one side and not the other, the thing wants to change its shape but it is held from being able to change its shape. Consequently it develops stresses inside which tend to cause failure if the temperature difference is too great. So we are interested in getting down to low rates of heat input. In this regard it so happens that the same solution applies. One of the features of these vehicles is that the heat rate is reduced if you increase the radius of curve on the surface, and that goes right along with the concept of using a fairly blunted shape. In other words, you would never use a pointed vehicle. If you have ever taken a needle and held it in a flame and looked at it with a microscope you find out, even if you just passed it through, the sharp point which was on the needle is gone because it has no heat capacity. It has no place for the heat to go so it simply burns it off. So the vehicle should be rounded all over.

CURRENT BALLISTIC MISSILES

At the present time the best solution has been the use of a blunt shape. Figure 212 shows the nose cones for four of the vehicles we have at the present time, the Thor and the Atlas, which are almost the same except for differences in weights, the Jupiter and the Polaris. The essential feature in all cases is that they are relatively blunt bodies. They are not long, skinny things we used to think were the right kinds of shapes. Of the four, two are protected with copper. Copper has some very good attributes and some rather poor ones, but it is good in that it has very high thermal conductivity. If you heat one end of a copper body the other end gets hot very rapidly. Consequently, there is very little trouble about thermal stresses developing to buckle the shell. On the other hand, it doesn't carry away as much heat per pound as some other materials do. Although it is very nearly as good as most metals it is not as good as some.

The more advanced Polaris uses beryllium which is superior to copper from the point of view that it will carry away more heat per pound. Consequently it is a better material from this point of view. On the other hand, it is not quite so good from the point of view of thermal stress, but it has been shown to be satisfactory in this particular case. In the case of the Jupiter, a different method is used. Glass fibers were used which were bonded with plastic. The idea here was not only to let this melt but actually to encourage it to melt and in fact encourage it to vaporize. It is a material with a poor thermal conductivity and it simply vaporizes.

It takes far more heat to vaporize something than it does just to bring it up to the melting point. You can carry away a lot more heat.

In fact it is a factor of about 10, in that order, between 10 and 30, so that it allows a big reduction in the weight of the heat shield. In the case of the Jupiter this was tried and found to work very well, and in fact the more modern schemes are based on the use of ablative surfaces; that is, surfaces that are purposely vaporized. Of course, we can get away with that because we don't expect to use it twice so if we lose some of the surface it is not an important point. So with the use of these ablative surfaces it is possible to greatly reduce this weight involved in the heat shield. There are some tricky problems about this that make it undesirable. But certainly this type of solution will probably find more use.

EFFECT OF SHAPE ON VELOCITY

There is one thing more that would be an advantage by using the ablative materials. Since the ablative materials carry away far more heat, we don't have to go to quite such blunt shapes. So this advantage of going away from blunt shapes is shown in figure 214. When the drag is high, there is a fairly long period in the altitude where the speed is low, and the principal disadvantage of that is that the vehicle is then subject to wind drift as it comes down, and although you may have locked it to the right locality, if it spends too long coming down it will drift off the target before it hits the ground. Consequently we would like to reduce the drag for this purpose if for no other. So the improved versions of ballistic missiles will go toward less blunt shapes than we use at present.

This is one of the things that is being done with the Minuteman, Since the days when the first vehicles were started, a lot has been learned about what we should not do again. Some people would term those the model T versions. They are a little more expensive than the model T's were but they are connected with it in a way. With the Minuteman we are taking advantage of a number of gains that have been made in propellants. Certainly in the field of improving guidance systems we are taking advantage of the improvements that have been made in the coolants for these nose cones and so on.

The result is that the vehicle is a lighter weight vehicle and fundamentally should be a better vehicle. What we would like to do is to bring these vehicles down to a size where they could be field-launched instead of having specific launching sites because it is too easy for somebody else to find out where you are going to launch from.

STRUCTURAL DYNAMICS

By Dr. John C. Houbolt, Assistant Chief, Dynamic Loads Division, NASA Langley Research Center, Hampton, Va.

The term "structural dynamics" may sound somewhat abstruse and therefore it is appropriate to give a definition of its meaning.

But before we define it, it might be well to point out how structural dynamic problems arise. It is a well-known axiom that all

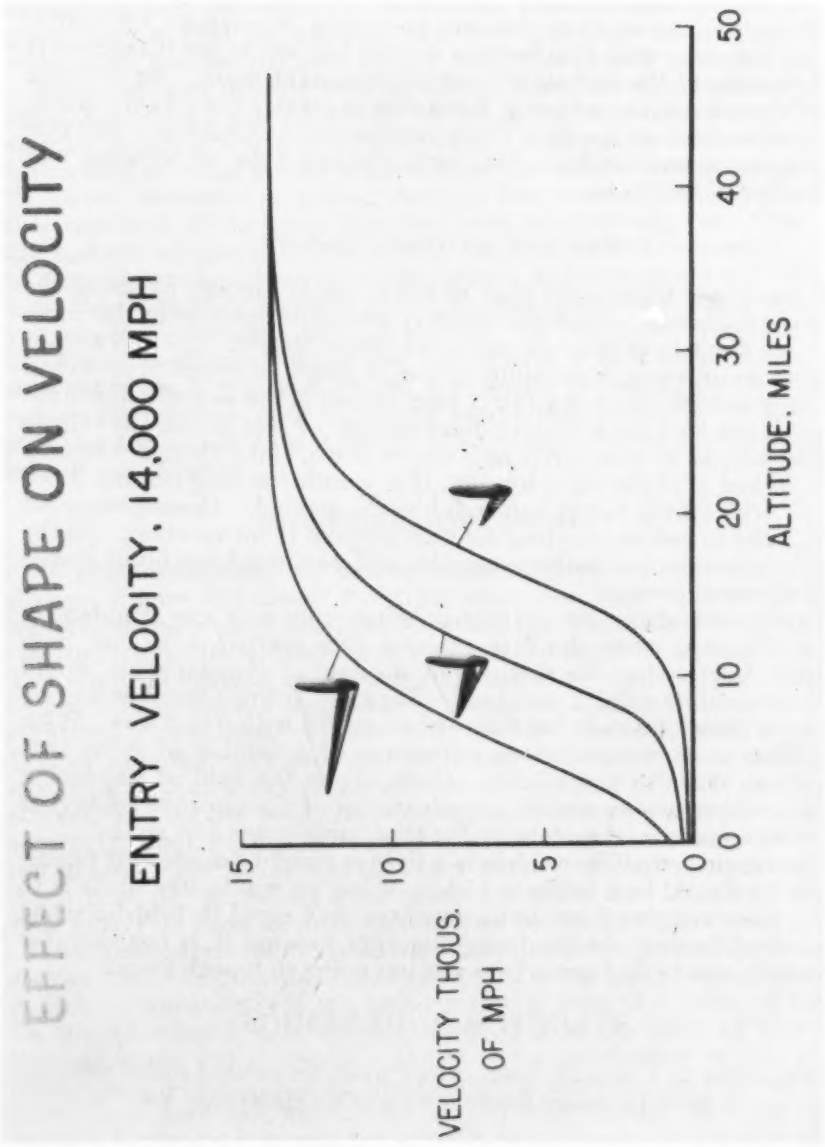

EFFECT OF SHAPE ON VELOCITY
ENTRY VELOCITY, 14,000 MPH
VELOCITY THOUS. OF MPH
15
10
5
0
0
10
20
30
40
50
ALTITUDE, MILES

FIGURE 214

flight vehicles must be designed to a minimum weight. Yet the structure provided must be strong enough to withstand the forces of flight. Now there are two types of forces that affect structural loads. One type of force is associated with maneuvering, such as turning, pull-ups, pushdowns and the like, and the other category is associated with the flexibility or vibratory characteristics of the structure. The flexibility or vibratory characteristics lead to the structural dynamics problems.

TYPES OF MOTION INVOLVED IN STRUCTURAL DYNAMICS PROBLEMS

Structural dynamics deals with the fact that our structural deformation and motion vary rapidly with time. There are three types of motion involved in structural dynamics problems. The three categories are free, forced, and self-excited.

The "free vibration" category can be demonstrated by a simple winged model. If we pluck the wings and then let them vibrate by themselves undisturbed, we have the phenomenon of free vibration. The modes of vibration may be very simple in form, or they may take on a very complex form. These vibratory characteristics are basic ingredients to all structural dynamics problems. Therefore, much of our research in structural dynamics is devoted to determining means for assessing and determining what these structural vibration modes are.

Because the vehicle systems that we are dealing with now have become so diverse and complicated in form, we are trying to build up our laboratory facilities to cope more adequately with these vibration problems.

The second category of structural dynamics is that of forced motion. In this category our structure is acted upon by external forces. An airplane flying through gusty air is an example where the turbulence of the air excites the wing into motion.

Another category is the problem of landing where the landing forces themselves excite the structure into motion. There are other problems of course of force vibration such as; the vibration of helicopter blades in the case of helicopters, the response of the aircraft when it is subjected to blast loads as might be encountered in the delivery of a nuclear weapon, or conversely, the use of a nuclear weapon to create a blast load to destroy an enemy aircraft.

There is one underlying factor about this category of forced motion and that is the basic philosophy that the structure must be designed to withstand all the loads that are imposed on it so that it will be structurally safe.

The third category is that of self-excited motion. This is the most difficult of all three to comprehend. It is a situation where the airplane structure can withdraw energy from some source and cause a natural inherent instability of the structure. Certain everyday examples are the flutter of a flag, the singing of a TV antenna, and we might cite the catastrophic example of the oscillatory collapse of the Tacoma Narrows Bridge.

We want to design vibrations of this category out of the structure. They are like fatal diseases and we want to avoid them. Therefore, much of our research is devoted to understanding the causes and the cure of these self-excited-type motions.

There is an instructive way of representing these various categories and that is afforded in figure 215. In figure 215 we show in the center the flight system itself. It is composed of inertia or mass, a stiffness which we represent here by a spring, a propulsion system, and then some aerodynamic surface.

Surrounding the system we have the various environmental fields through which the system flies. By considering isolated parts of the diagram and their interaction we can demonstrate the various categories that we have just defined.

For example, if we consider just the mass and the stiffness, we have the category of free vibration. If we add to it the aerodynamic surface, and the flight media such as air, we would have the problem of flutter. Adding, say for example, the atmospheric disturbance such as turbulence, we would have the problem of forced motion, and so on around the figure.

It might be well now to look briefly into some of the current sources of structural dynamics problems.

SOURCES OF STRUCTURAL DYNAMICS PROBLEMS

Figure 216 shows the sources by referring to a launched supersonic or hypersonic vehicle in three different phases; the ascent, the orbiting, and the descent. We can regard the ordinate as the altitude. In the ascent phase, for example, there is a prelaunch problem which might be described as the smokestack oscillation of the missile in the prelaunch condition. At a little higher altitude we run into the gust problem.

A little higher on we run into severe acceleration loads or the noise problem due to the jet or rocket engine. Jet noise in which structural failures of this type can be encountered in a matter of a very few minutes due to the intense action of the noise and jet forces has been adverted to. A little higher on the severe aerodynamic pressures may lead to self-excited motions.

Further around figure 216 we run into our various sources of structural dynamics problems. Two of the problems may be demonstrated with the aid of a wind tunnel, whose purpose is to draw a wind over the vehicle model, which is in launch position. As the wind velocity increases, the modely vibrates and becomes slightly unstable. This is a self-excited type motion. In certain situations this motion can become quite intense and actually cause the model to fail.

Another type of instability which can be encountered under certain high-speed flight conditions is called divergence. This is a condition wherein the vehicle actually deforms due to hypersonic wind velocities, resulting in vehicle failure. This, of course, must be avoided at all cost in the consideration of the flight of vehicles.

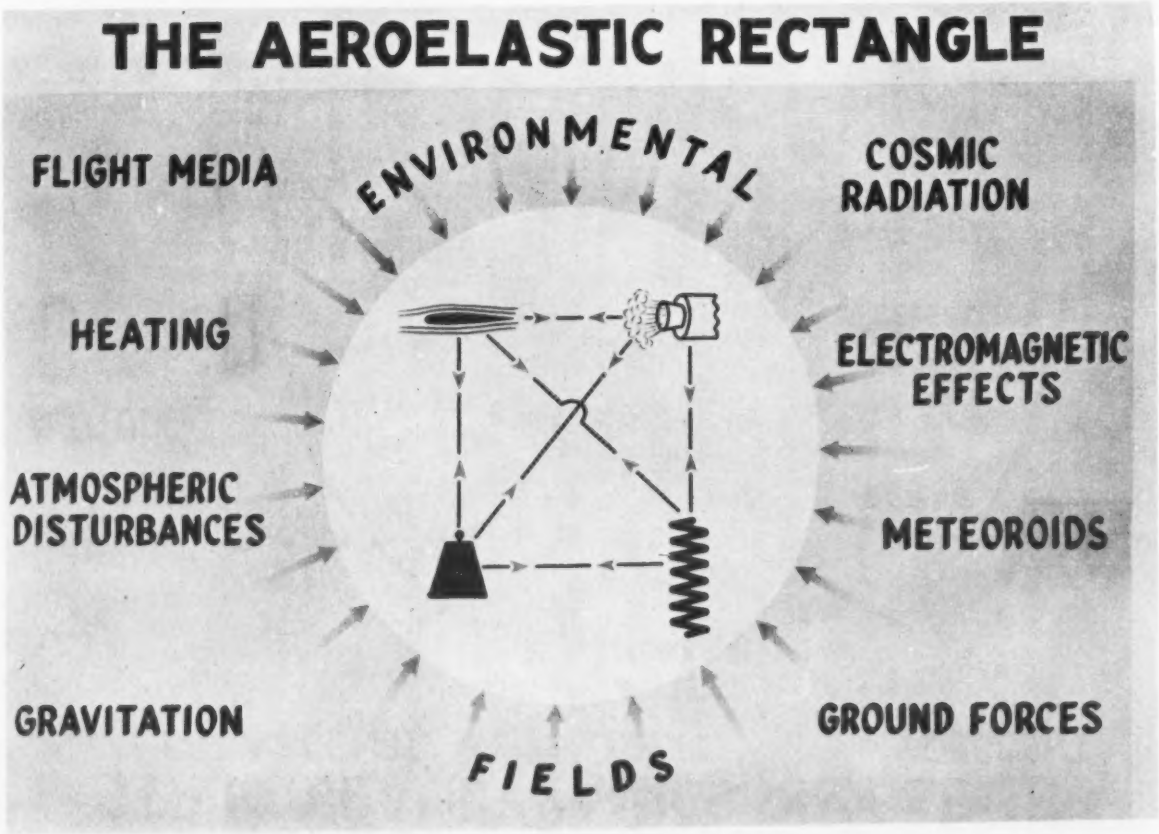

THE AEROELASTIC RECTANGLE
ENVIRONMENTAL
FLIGHT MEDIA
COSMIC RADIATION
HEATING
ELECTROMAGNETIC EFFECTS
ATMOSPHERIC DISTURBANCES
METEOROIDS
GRAVITATION
GROUND FORCES
FIELDS

FIGURE 215

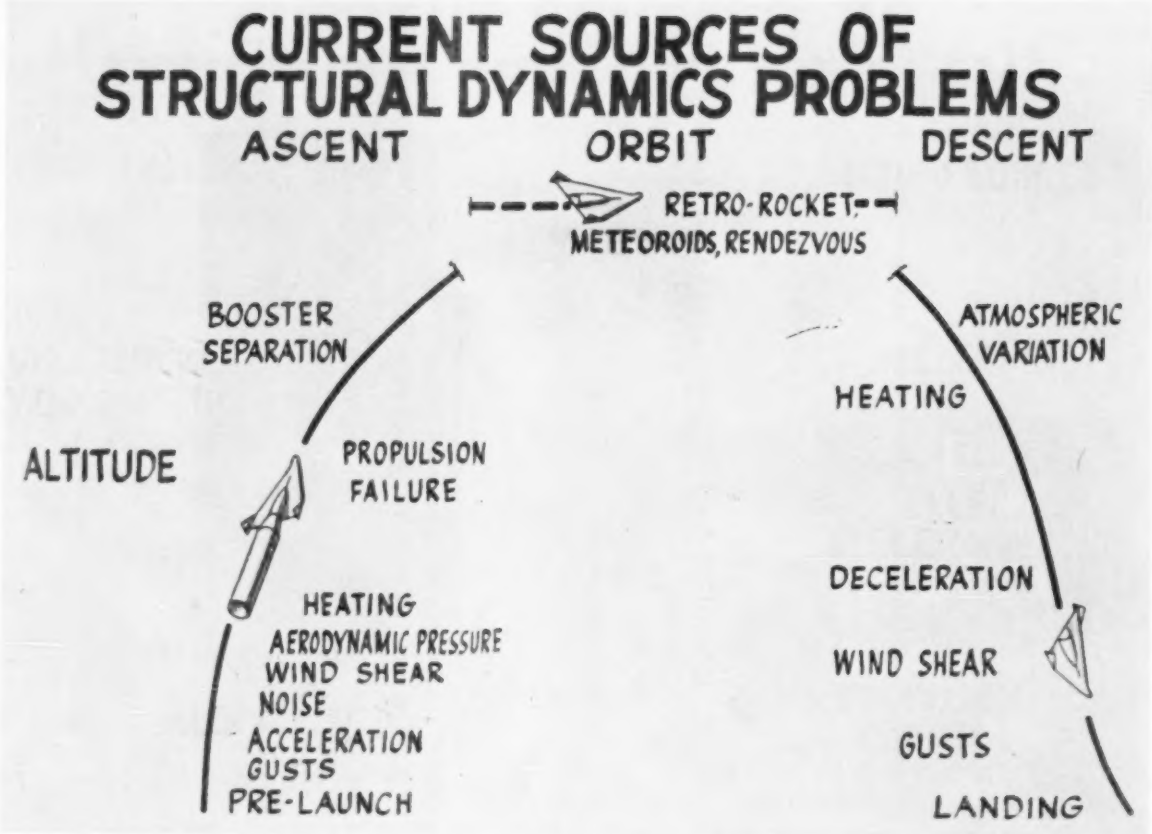

CURRENT SOURCES OF
STRUCTURAL DYNAMICS PROBLEMS
ASCENT
ORBIT
DESCENT
RETRO-ROCKET
METEOROIDS, RENDEZVOUS
BOOSTER
SEPARATION
ATMOSPHERIC
VARIATION
HEATING
ALTITUDE
PROPULSION
FAILURE
DECELERATION
HEATING
AERODYNAMIC PRESSURE
WIND SHEAR
WIND SHEAR
NOISE
ACCELERATION
GUSTS
GUSTS
PRE-LAUNCH
LANDING

FIGURE 216

Figure 217 shows some of the current structural dynamics problems; we have mentioned a few but by way of reemphasis we call attention to a specific few. We have shown here a certain type of vehicle. It could represent a rocket vehicle system or it might be representative in schematic form of a flexible airplane. We can run into the problem of wing flutter, panel flutter, and control flutter as well as divergence.

Panels forming the exterior structure can be damaged by noise excitation. Or this excitation may come from the boundary layer or so-called aerodynamic noise. The body itself of the missile may be so flexible that we run into body deformation problems. This can couple with severe fuel sloshing problems within the missile. The engine or jet exhaust may be rough in its burning. The control which actuates the jet may interact with the body formations to lead to an instability called the control-structure interaction trouble. So this chart simply points up some of the current structural dynamics problems that we are doing research work on.

Now what has some of this research taught us in the field of structural dynamics? On this chart we summarize some of the recent NASA flutter studies.

FLUTTER STUDIES

Figure 218 shows the type of vehicle that was tested and the components on the particular vehicle. In the left column we note that the vehicles are primarily of the airplane type whereas on the right they are primarily of the missile type. The letters shown are abbreviations. "HT" stands for the horizontal tail, "W" stands for the wing, "VT" stands for the vertical tail, "TEE T" stands for a "T" tail. Over half of the vehicles tested had to be altered because of flutter troubles. Figure 219 shows an indication of the flutter and flight boundaries that have been found for certain wind tunnel studies.

By plotting the stiffness that is in the structure as a function of the speed we are able to see how strong or how stiff we have to build the structure in order to prevent flutter while operating within the flutter region.

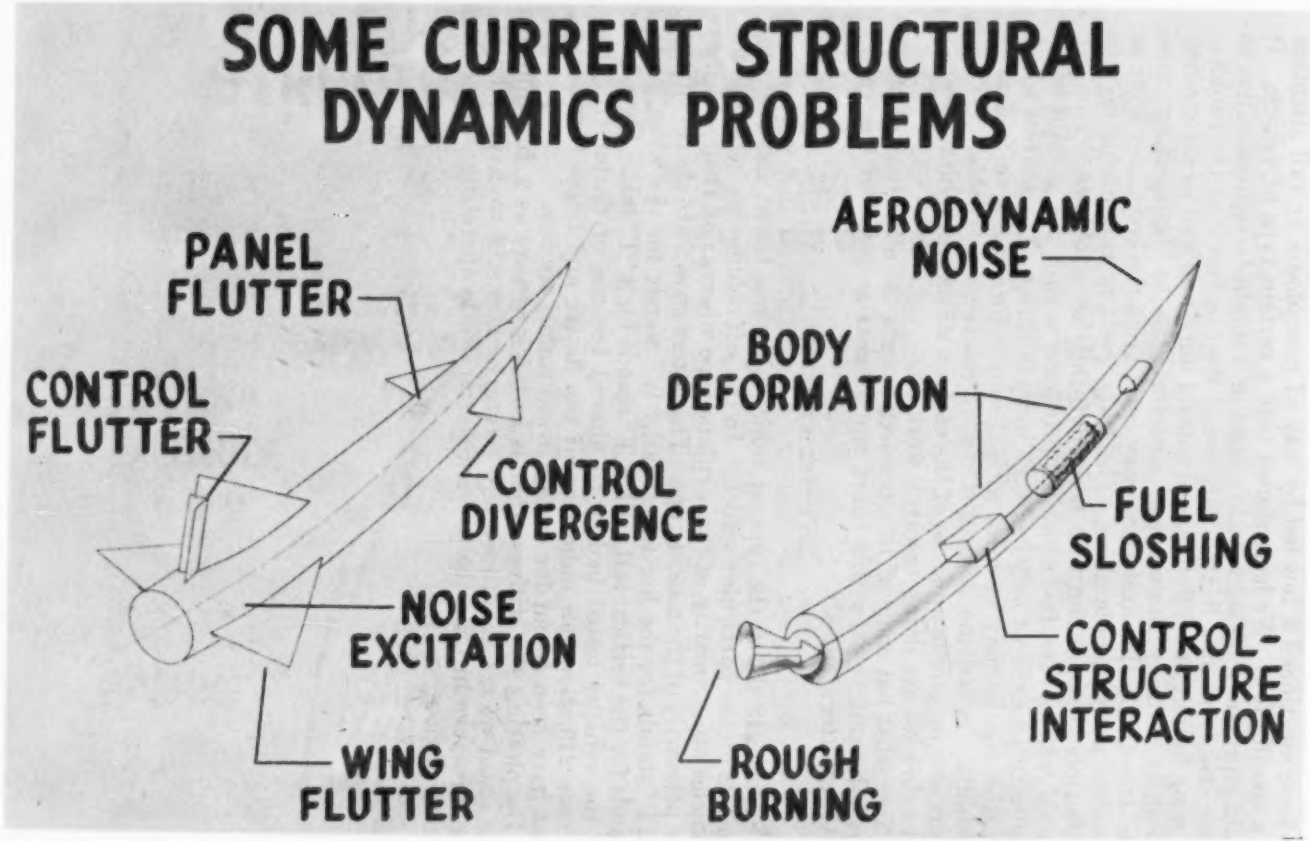

SOME CURRENT STRUCTURAL DYNAMICS PROBLEMS
PANEL FLUTTER
CONTROL FLUTTER
CONTROL DIVERGENCE
NOISE EXCITATION
WING FLUTTER
AERODYNAMIC NOISE
BODY DEFORMATION
FUEL SLOSHING
CONTROL-STRUCTURE INTERACTION
ROUGH BURNING

FIGURE 217

RECENT NASA FLUTTER STUDIES

VEHICLE	COMPONENTS	VEHICLE	COMPONENTS
RF 84F	HT	WS 302A	W
F 94	W	X-1E	W
F 101A	W	X-15	W, VT, HT
F 103	W, VT, HT	REDSTONE	VT
F 104A	TEE T	BOMARC A	HT
F 105A	VT, HT	BRASS BELL	PANELS
F 105B	W, VT, HT	TITAN	PANELS
F 8U-3	W, VT, HT	B-58 (CBP)	VT, CANARD
F 11F-1	W	CORVUS	W
XP6 M	TEE T	BOMARC B	W
YP6 M	TEE, T	ASROC	VT
WS 110A	W	G-91	HT

FIGURE 218

(NOTE.—HT=horizontal tail; W=wing; VT=vertical tail; TEE T="T" shaped tail. Underlined letters indicate that flutter was actually encountered. Those not underlined were flutter free.)

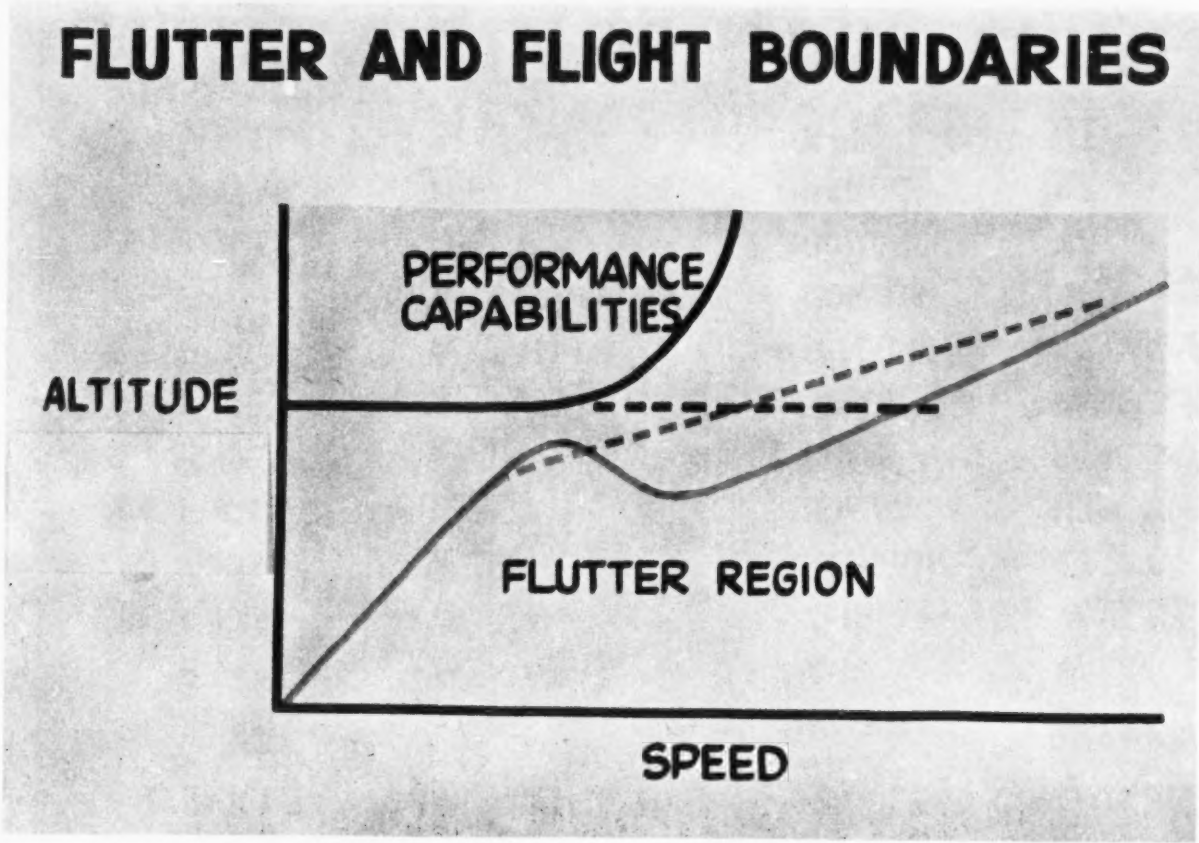

FLUTTER AND FLIGHT BOUNDARIES
PERFORMANCE CAPABILITIES
ALTITUDE
FLUTTER REGION
SPEED

FIGURE 219

Now the actual shape of this boundary of course depends upon the particular type of wing or configuration that we are testing. Some wings follow the boundaries shown by the solid line, some the boundary shown by this dotted line. The hump usually occurs, if it does, at a speed that is sonic speed, that is around 700 miles per hour.

I should mention in this connection that our research know-how and facilities are quite good into speeds up just beyond the sonic speed. But we need to extend our research into the much higher speed ranges, that is the hypersonic range, because here our facilities tend to become inadequate.

In considering this type of flutter boundary, we can also judge it from the point of view of the performance capability of the aircraft. We can equally well consider this ordinate here to be altitude instead and thus if we look at it in terms of altitude versus speed, we can add to it a curve which refers to the performance capability of the airplane.

Merely increasing the power capability of a given airplane does not automatically extend its performance capability, for the increased speed resulting from the increased power may well put us back in the flutter region. So it is boundaries, of this type that we must define in order to be able to avoid the problem of flutter.

Figure 220 shows some additional results of flutter obtained in the study of the proper position on the wing to mount an engine, for example, in order to obtain the maximum flutter speed. This chart shows, for example, a sweptwing airplane, and studies were made with an engine mounted at various locations to determine the associated flutter speed. The results indicate, for example, that an engine based anywhere along the line marked 700 would lead to a flutter speed of 700 miles per hour, and so on.

Looking at these curves, we can see obviously the best place to mount the engine. It is for the very reasons shown in this chart that airplanes such as the 707, DC–8, B–58, and so forth have their engines placed outward on the wing and so far in the forward direction of the wing.

DYNAMIC LOADS IN MISSILE DESIGN

Figure 221 shows some of the factors that are involved in designing a specific missile. We show loads that are due to static and dynamic sources, such as winds, engine, gusts, engine hard-over, and noise, and their tendency to break the missile.

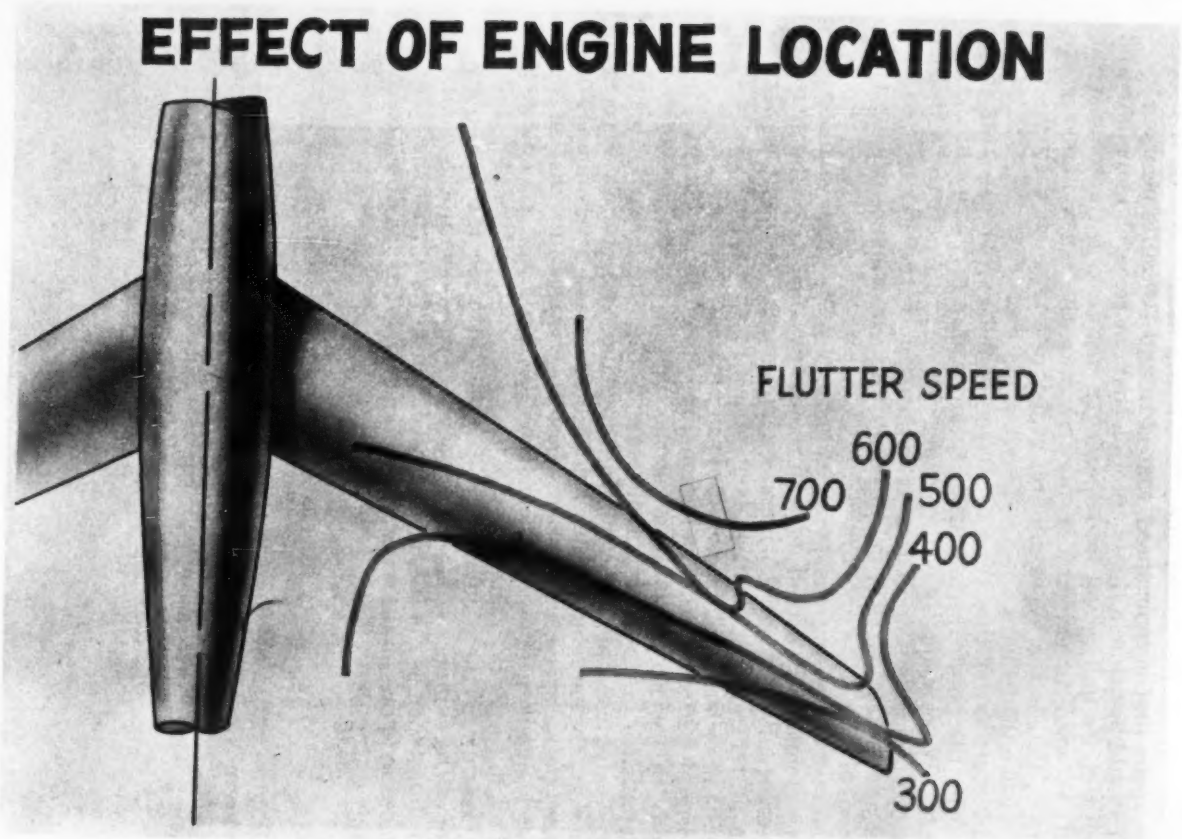


FIGURE 220

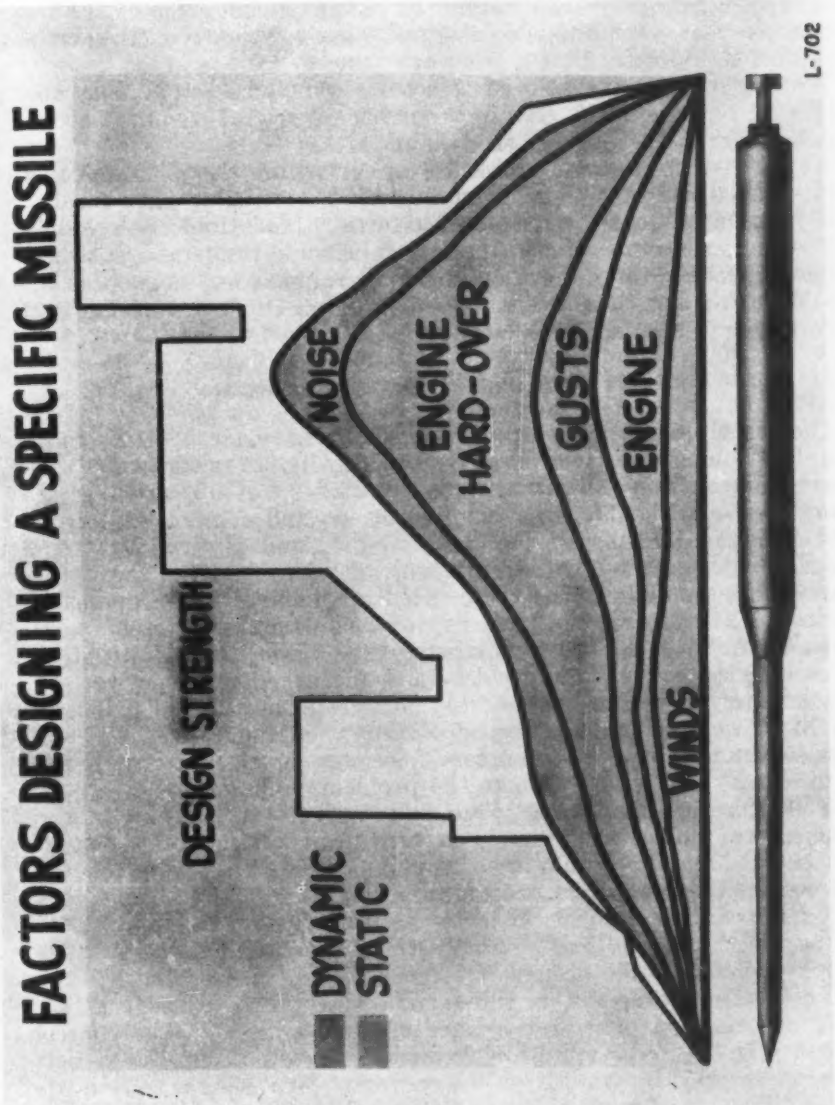

FACTORS DESIGNING A SPECIFIC MISSILE
DESIGN STRENGTH
DYNAMIC
STATIC
NOISE
ENGINE HARD-OVER
GUSTS
ENGINE
WINDS
L-702

FIGURE 221

We notice that the dynamic load sources here are by far predominant and exceed the static by several times. The outer curve shown in the diagram is the actual design strength that was supplied to the missile in its design. Now in some of the preliminary or early flyings of this particular missile certain failures were encountered. The fact that certain failures were encountered indicated that some of the information that went into the design was not sufficiently well known. and thus it indicates that more work is needed along these lines.

We can see that the field of structural dynamics is a curious one in that it represents the merging together of several technical areas, the structural areas and the aerodynamic areas.

As with most research problems, our attack on the problems is a multifaceted attack. We must employ wind tunnels, we must employ analytical means, use of models and so forth. I mentioned before that our coverage is quite fair in the low supersonic range and subsonic range, but our coverage in the hypersonic range is not as good as we would desire, and therefore we are making an effort to improve our coverage in this area.

RECENT STRUCTURAL DYNAMICS PROBLEMS

The structural dynamics problems which have received the most attention during the last year have come to light through the experience gained from the initial flight tests of the X–15; from wind-tunnel tests of the Dynasoar configurations and components; from development problems on the Scout vehicle and Project Mercury; and from design study of the dynamic requirements for the upper stages of Saturn. Some of these problems include the following:

Panel flutter.—Wind-tunnel tests of heat shields for reentry vehicles have shown that the type of structure which has been proposed to relieve the heat stress problem, has a marked tendency toward panel flutter. This has necessitated changes in heat shield panels of the X–15 airplane and on Project Mercury. Although certain solutions of the problem have been found, research work is continuing so as to obtain a better solution to the problem. The use of hydrogen as a fuel for the upper stages of our space vehicles, such as on Centaur, Saturn, etc., makes it necessary to provide insulation of the tanks which will have the capability of surviving the forces from the airflow as the vehicle passes out of the atmosphere. Here, too, panel flutter appears to be a critical factor needing further work.

Body deformation and control structural interaction.—A very severe problem in the design of large boosters, such as Saturn and Dynasoar configurations, is the instabilities which arise from the body deformation or vibration modes interacting with the control system. If the body vibration frequencies are too low, the vehicle cannot be guided by gimballing the engines. In a design study made of the Saturn configuration, it was found that this was the dominant consideration in the selection of the upper stages of the vehicle. Cur-

rently, studies are underway to increase the frequencies of booster systems. Studies are also being made of other types of control systems which will not require such high structural frequencies to obtain stability.

Landing problems of reentry vehicles.—Reentry vehicles which are designed to fly like airplanes are usually very long slender vehicles which land at a high angle of attack. This requires that the main landing gears, which are usually skids, be near the tail of the aircraft. After the main gear touches down, the nose wheel usually comes down hard. The X–15 is an example of this type of vehicle and, as is well known, in one emergency landing it came down so hard as to break the fuselage. The experience gained from the X–15 has pointed to a number of new dynamic problems. The solutions which have been obtained on the X–15 have a direct application to reentry vehicles such as Dynasoar.

Wind vibration problem.—The wind vibration problem is of continuing concern with regard to the Scout vehicle. A program has been undertaken to measure the dynamic stresses on the Scout vehicle while on the launch stand at Wallops Island Station. The effect of various devices such as spoilers will be evaluated. A companion wind-tunnel program on models is also planned to improve the methods of wind stress prediction.

Wind shear and environments.—The critical loads on a vehicle are often determined by the wind shear and the engine forces necessary to maintain control. Recently a new method has been developed, based on photographing the smoke trails, which will make it possible to define the fine structure of the wind variations. This method is now in use at Wallops and will be put in use at Patrick Air Force Base. This information will make it possible to better define the loads to which the vehicle is exposed, and thus provide information for future designs. Progress is also being made on obtaining the vibration and noise environments for the payloads of future vehicles, and facilities are planned to superpose these environments in the laboratory so as to improve the reliability of the payload and equipment.

INTERCEPTOR MISSILES

By David G. Stone, Head, Stability and Controls Branch, Pilotless Aircraft Research Division, NASA, Langley Research Center, Hampton, Va.

The research work NASA is doing in support of defense against ballistic missiles, and the areas in which we are working now are outlined in figure 222.

In the defense against ballistic missiles, we are looking into anti-missile missile requirements, what is required of the weapons system; that is, missile configuration research, what kind of missile would you use, and the detection of bodies entering the earth's atmosphere.

And in an allied field we are looking into the subject of antisatellite weapon systems. The first thing to do in this work is to study the threat; that is, what are the basic concepts involved, so we will know where the research problems exist.

53795 O—60—pt. 2——26

INTERCEPTOR MISSILES

DEFENSE AGAINST BALLISTIC MISSILES

ANTI-MISSILE MISSILE REQUIREMENTS
MISSILE CONFIGURATION RESEARCH
DETECTION RESEARCH

ANTI-SATELLITE WEAPON SYSTEM

FIGURE 222

ANTI-ICBM POINT DEFENSE

We refer to the point defense question and look for areas that could lead to research. I will explain in detail how the missile will work. First it will be launched vertically or near vertically for reasons of safety and reliability and guidance. So first there will be a booster that will lift the missile above the ground and boost it to a very high speed. Then the missile part of this vehicle will turn to get its payload lined up with the flight path. During this turn it also must accelerate so it can get to the point in time. It will then continue to coast. It won't lose mush velocity because we don't have much air up there any more.

Now one thing to note is that the ascending turn will be made mostly within atmosphere. This means that we can use aerodynamic means to turn it. And so one of the problems right away is can you generate enough aerodynamic lift to turn this missile?

Can you use aerodynamic controls to tilt it so you can generate this lift to turn at high speeds? Can it withstand the aerodynamic heating and have structural integrity? The NASA has run wind tunnel and other tests to give answers to these points.

ANTIMISSILE CONFIGURATIONS

The anti-missile-missile configuration is ultimately determined by the time available after an oncoming ICBM has been detected, for this time period determines the velocity which the missile must attain to reach intercept position. Velocity, in turn, dictates the aerodynamic lift which the controls must generate in order to turn the missile toward its target. Thus from the warning time, as it dictates velocity we must determine whether aerodynamic controls or reaction controls are better for the missile.

NASA has completed the greater part of the aerodynamic research on a configuration using aerodynamic controls which it believes capable of fufilling the velocity demands of the missile. However, there still remain flight testing and mach 10 wind tunnel studies to determine altitude effects on aerodynamic controls. These wind tunnel studies must await completion of larger hypersonic test facilities.

REENTRY DETECTION RESEARCH VEHICLE

NASA has started an investigation looking toward lengthening the warning time, thus decreasing the required velocity. There is a peculiar aerodynamics phenomenon that takes place upon reentry into the earth's atmosphere, and this is the phenonemon of ionization.

In other words, when a high speed body comes in it collides with the molecules of the air as it enters the rarefied gas, which is the atmosphere. Electrically charged particles are given off and they stream out and behind in an aerodynamic fashion like an aerodynamic wake. This is usually called an ion sheet. This ion sheet will act like a billboard or a reflecting board for the radar and will enhance its radar signature echo. Now, theorists have indicated that this ionization is quite large, but in any event the theory that indicates that this effect will be large is inadequate and therefore another experiment is in order to establish this.

In figure 223 is shown a scheme for studying the detection of reentry bodies on an economic scale which is much less costly than using a full scale ICBM for this research. There is shown here a complete vehicle, the trajectory which is a profile of the flight plan, and the velocity package.

Stages 1, 2, and 3 of the complete vehicle are only elevator stages or altitude getters to get the final No. 4 or velocity package up to a required altitude. The motors of stages 1, 2, and 3 fire and drop off successively. The velocity package is then coasting along by itself and when it gets to about 200 miles up, it goes to work. Within this velocity package are three more rocket motors. The velocity package may be regarded as a flying launching tube the bottom of which is now open. When we reach the peak altitude, motors Nos. 5, 6, and 7 will fire in quick succession. This motor No. 7 is a special spherical motor specially designed and developed by NASA.

When this spherical motor fires, is in the reentry object that we are going to look at and detect, and it is at ballistic missile speeds, that is in the order of 16,000 miles per hour from about 160 miles down to about 30 miles. We are going to be looking at this with radar and optical means and every means that is available for detecting objects entering the earth's atmosphere.

I would like to repeat that this is a more economical scheme than using ballistic missiles. Also you will note that at the indicated range we are in close so that most of our instrumentation is relatively closely confined.

The Defense Department and other agencies have shown a keen interest in this investigation, and we have welcomed their cooperation. In fact we have a cooperative program with the Lincoln Laboratory, since they have most of the radars to look at it.

Another aspect that I would like to mention is this. We have launched the initial vehicle in this program and it was qualifiedly a success so now we are going ahead.

WARHEAD-STAGE DYNAMICS

Another problem which we are studying, but as yet have no experimental phase, is what goes on in the warhead-stage capability zone. In other words, the ground-based radar will guide the steerable stage up to where it is about in front of the incoming enemy ICBM. At that time the warhead stage will separate from the missile, and it will have its own propulsion and its own guidance, that is a seeking system of some sort, and its job is to shove itself over in front of the ballistic missile, so that it is right exactly in front of this incoming path. There are two problems here.

One is that at the time that you decide to do this time is very short. Also seeker ranges are limited. That means we have to put more propulsion into the steerable stage and better guidance into the steerable stage, which will run up the weight of the whole vehicle and then we might be defeated in that direction. So there are definite limitations that you can go either way. One of the important things here is we are back to a detection problem again. Most likely we are in space so there will not be any deterioration of this radio or optical propagation signal in space, so we are looking into an experiment now

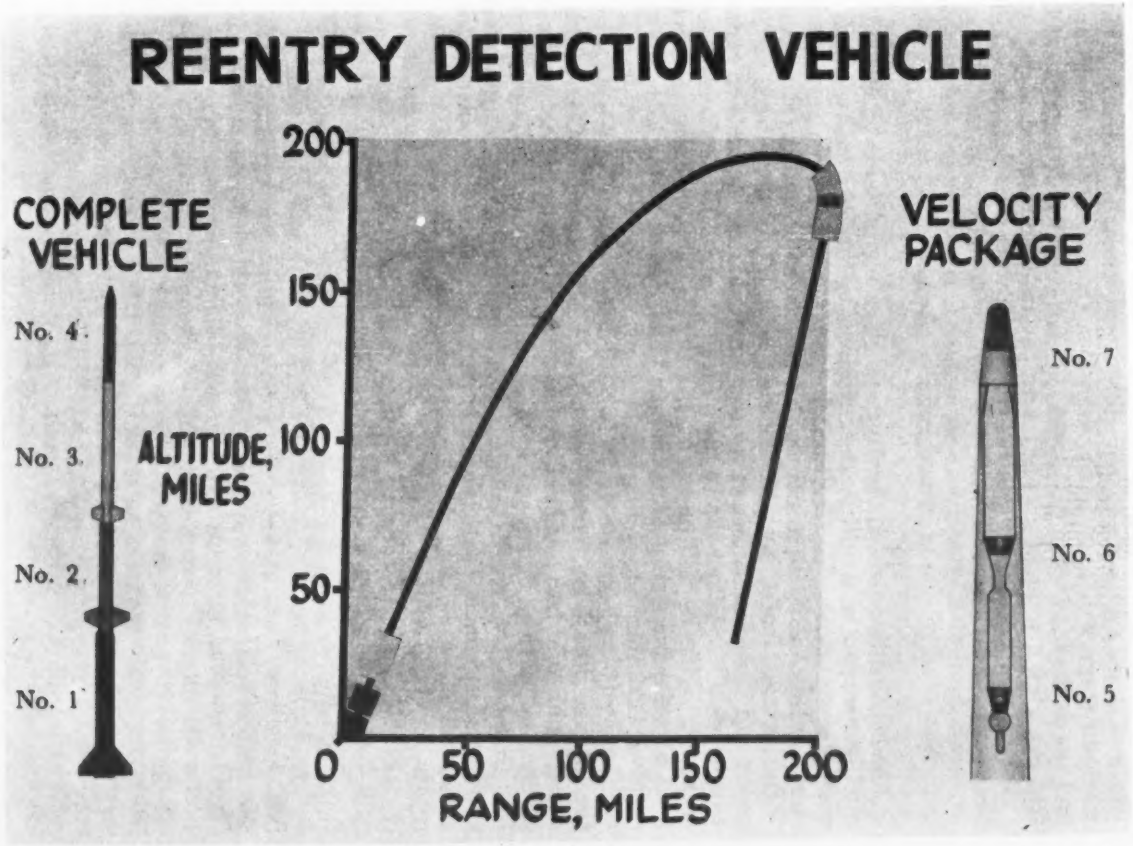

REENTRY DETECTION VEHICLE
COMPLETE VEHICLE
No. 4
No. 3
No. 2
No. 1
ALTITUDE, MILES
200
150
100
50
0
50
100
150
200
RANGE, MILES
VELOCITY PACKAGE
No. 7
No. 6
No. 5

FIGURE 223

to look at a high-speed object in space while the looking device is also at high speed in space. Also, this could apply to rendezvousing with a satellite as well as the anti-ICBM problem.

Another thing that has to be done is that it is possible that the warhead stage will be used at much lower altitudes. In that case this warhead stage will have to fly sideways, frontward, and backward, and the aerodynamics might upset it. We need wind tunnel tests to find out what are the upsetting forces here to take into consideration.

We are analyzing the problems concerned with area defense. This has shown so far that much more knowledge needs to be gained.

ANTISATELLITE MISSILE

The other allied field is the antisatellite. The mission of the antisatellite weapon is to nullify the information that the enemy obtains with the reconnaissance satellite. I don't mean necessarily knock it down, but to nullify it so no one can get the information off of it.

In the scheme of things, the satellite orbit might be as high as 400 miles, and it will come into range at which time the acquisition radar will acquire it. When the satellite is in position the launch of the antisatellite missile will be made. Again we can ask ourselves what kind of a vehicle will get up there. This does not come out to any extravagant thing.

What we found out so far in this analysis is, that problems with the antisatellite are similar to the anti-ICBM in that we need to study a staging of solid fuel rocket motors, detection in space, detection from the ground of things in space, because the atmosphere will act like a lens that we don't want to look through, and problems of guidance and aeroelasticity. All these are things that we need to do for the antisatellite.

VII. THE LIFE SCIENCES PROGRAM

By Clark T. Randt, M.D., Director, Office of Life Science Programs, NASA

The Office of Life Science Programs was established as a fifth major division of the National Aeronautics and Space Administration on March 1, 1960. The role of the life sciences, which include medicine, biology, and psychology, in the space effort was considered comprehensively by the Bioscience Advisory Committee appointed by NASA Administrator T. Keith Glennan in July 1959. The members of this group were selected on the basis of their scientific eminence and their individual stature rather than for any prior interest in the space program. Dr. Seymour S. Kety, Director of the Clinical Science Laboratory of the National Institutes of Health, was Chairman. Members were Dr. Wallace O. Fenn, professor of physiology, University of Rochester; Dr. David R. Goddard, director, division of biology, University of Pennsylvania; Dr. Donald G. Marquis, professor of psychology, Massachusetts Institute of Technology; Dr. Robert S. Morrison, director of medical and natural sciences, Rockefeller Foundation; and Dr. Cornelius A. Tobias, professor of medical physics, University of Califorina. The committee was informed of the personnel, equipment, facilities, and programs in the military aviation medical laboratories by 17 members of the Armed Forces. University and industrial representatives presented background information in their respective areas. The report of the ad hoc bioscience advisory committee was submitted on January 25, 1960. It has provided useful guidelines for the NASA Life Science Programs. This document is available to those who are interested in this aspect of the space program.

DUAL ROLE OF LIFE SCIENCES

The consensus of opinion among members of the Committee, and others who were consulted, was that the life sciences have a dual role in the exploration of space: To promote scientific and technologic advances related to manned space flight; and to investigate the effects of extraterrestrial environments on living organisms including the search for extraterrestrial life. The same reasons which prompted the establishment of NASA and gave it responsibility for all space activities devoted to peaceful purposes, in accordance with the Space Act of 1958, require that NASA assume responsibility for leadership, coordination, and operation of the biomedical aspects of this national space program.

The objectives of the Office of Life Science Programs are to implement manned space flight to assure man's contribution to the success of space flight missions and to utilize his unique capabilities as a scientific observer in space exploration; and to conduct biological investigations to determine the effects of remote environments on living organisms including the search for extraterrestrial life. The lat-

ter effort can be expected to contribute knowledge pertaining to the origin of life and its evolution in the universe which is a goal for scientific achievement in the total space program.

Research, development, and training required to implement manned space exploration and to conduct significant biological investigations utilizing extraterrestrial environments for observation of biologic phenomena may be considered in three broad categories: first, flight medicine and biology; second, space medical and behavioral sciences; and, third, space biology.

BIOTECHNOLOGY

Flight medicine and biology include two applied or technological areas concerned with in-flight operations. The first, biotechnology, may be defined in terms of man-machine integration and instrumentation; man's stress tolerance limits and means of adaptation thereto; protective equipment, including radiation shielding, and escape devices; controlled environment life support systems; crew performance; and public health and ground crew safety. Activities in these areas are conducted to assure man's protection and his ability to perform in advanced space systems. The ultimate benefits which may accrue from manned space flight are, in large measure, unknown. It is clear, however, that instrumentation alone is unlikely to reveal as much information about the moon or the planets as man is capable of observing once he has visited these remote places. Man's ability to make a wide variety of unprogramed observations and when necessary, to analyze them expeditiously and with flexibility, his decisionmaking ability, and his resourcefulness for onboard maintenance and repair of some of the complex space flight systems thereby contributing to the reliability and ultimate success of a space flight mission dictate a requirement for continued effort in manned space flight projects. The Office of Life Science Programs will support Project Mercury in every way possible; however, no change in the management or operation of this top priority program is contemplated. This Office will be intimately concerned with the follow-on manned space flight projects and anticipated biotechnical problem areas related to the NASA 10-year plan, specifically the circumlunar mission and manned lunar landings with return to earth.

BIOMEDICAL EXPERIMENTS IN EXTRATERRESTRIAL ENVIRONMENTS

The second technological area of effort within flight medicine and biology is concerned with biomedical experiments in extraterrestrial environments. In-flight studies designed to evaluate survival and performance in animals are in one category, and basic biological investigations to be conducted in a variety of space environments comprise another. Such experiments contribute to (1) manned space flight feasibility, and (2) the determination of the effects on living terrestrial organisms of conditions existing in the upper atmosphere, in space, on the moon, and in other planetary environments as well as to the search for extraterrestrial life.

The opportunity now exists to conduct fundamental life sciences research in satellites and space probes. The space environment presents a new dimension for observation of biologic phenomena. The

ultimate goal is the identification and study of life, its precursors, or remains, on the moon and planets. This accomplishment would lead to knowledge pertaining to the origin of life and its evolution.

Immediate interest centers on the conditions of the space flight environment that are irrevocably different from the terrestrial, namely, unfiltered radiations and the altered gravity state. The former is qualitatively and quantitatively different from terrestrial radiation. It has far-reaching implications regarding future manned space flight missions as well as offering opportunity for further delineation of the subcellular ionizing effects from a basic biological viewpoint. The weightless state presents the opportunity for determining its effects in animals and men subjected to long duration removal of the constant stimulation of specialized bodily sensors by the force of gravity, and, elucidation of biological processes affected by weight or apposition of one part against another, such as cell division and morphogenesis. Also, interaction at gas-fluid interfaces and other physicochemical phenomena may be altered with significant consequences in living systems.

PRIOR ANIMAL TESTS NECESSARY

The hazards of space flight are such that tests to insure survival and meaningful performance must be determined with animals prior to subjecting man to this experience involving application of combined stresses which can be expected to alter the distribution of blood flow to vital organs including the brain, heart, lungs, and kidneys, as well as the neurological consequences of long-term altered sensory input as it affects internal regulating systems and mental processes. In-flight tests of life support systems as regards their long duration adequacy, efficiency, and reliability in maintaining a habitable artificial environment must precede each manned mission.

Biological studies conducted at a cellular and subcellular level in extraterrestrial environments, in addition to those concerned with radiation and weightlessness, will include observation of the effects of high vacuum, temperature extremes, and the unusual combinations of elements to be found in remote planetary atmospheres and surfaces. These investigations can be profitably extended by extra-atmospheric spectroscopic studies directed toward more precise identification of extraterrestrial life-supporting substances and development of instruments for use in collection and analysis of extraterrestrial organic compounds and possible life forms.

Biomedical experiments in extraterrestrial environments will evolve from ground-based investigations conducted under the auspices of the Office of Life Science Programs and the staff of the sections of space medical and behavioral sciences and of space biology with full utilization of support from the scientific community. In general, until manned orbiting laboratories become available, these experiments will preferably be conducted with recovery of exposed specimens for study, or, less effectively, with telemetry of results from space probes. At least one satellite or space probe per year should be devoted primarily to biomedical investigations, in addition to those experiments conducted on a space-available noninterference basis in other spacecraft. Weight, volume, power, and reliability considera-

tions are to be coordinated with the launch vehicle schedule and physical science experiments in specific detail. Planning, programing, and participation in payload design, assembly, testing, operation, and data evaluation will be conducted by the section on flight medicine and biology.

GROUND-BASED SUPPORT RESEARCH

The section on space medical and behavioral sciences is concerned with ground-based research for long range support of manned space flight missions in the disciplines of radiology, metabolism, cardiovascular physiology, respiratory physiology, neurophysiology, and psychology. This effort is to provide basic metabolic, physiologic, and psychologic contributions for implementation of manned space flight, and, to observe and study the fundamental aspects of the reactions of animals and men involved in space flight and exploration as they relate to survival and performance.

As manned space flights become voyages of days, weeks, or longer duration, there is need for a more fundamental approach to problems involving the basic medical and behavioral disciplines of radiology, metabolism, cardiovascular physiology, respiratory physiology, neurophysiology, and psychology.

Physical measurements of the radiations in space have defined requirements for more precise evaluation of the effects of long-term, relatively low doses of ionizing radiation and for development of means of protecting therefrom, in addition to conventional shielding techniques. Altered metabolic reactions by pharmacologic means hold promise for affording varying degrees of protection from radiation resulting from exposure to sources of energy in the electromagnetic spectrum as occur in space flight.

Metabolic requirements of animals and men in terms of energy exchange, heat transfer, and musculoskeletal effects under the limitations imposed by confinement in an artificial space capsule environment pose problems of a fundamental nature which are worth of continued study.

Acceleration forces and weightlessness produce a redistribution of blood flow to the heart, brain, and kidneys. The chronic effects of physical force stress on these vital organs and possible adaptation thereto, as well as the long-term cardiovascular effects of restricted mobility are subjects for more detailed scientific consideration.

Long-term living in an artificial atmosphere which can be expected to deviate from optimal conditions, on occasion, necessitates further study of the process of diffusion of gases including toxic substances from the lungs to blood and from blood to body tissue as well as more penetrating consideration of the chemical control of pulmonary ventilation and tissue respiration.

More detailed knowledge of nervous system sensors; visual and auditory perception and elaboration; the physiologic substrate of orientation, thought, and emotion; the neural control of respiration, cardiovascular function, temperature, and metabolism; and the neurophysiological aspects of environmental adaptation and fatigue, as well as psychological reactions involved in motivation, vigilance, and social adjustment, reflect a series of important areas of concern in regard to man's performance under conditions imposed in flight.

Investigations in the basic medical and behavioral sciences will also contribute knowledge in these areas which will result in a better understanding of health and disease on earth.

Radiation hazards in projected manned space flight missions to the moon and planets make radiology a primary area of effort. In addition to the ambient radiations in space, the proposed use of nuclear energy for auxiliary power and for propulsion lend additional emphasis to this field.

Stimulation of interest and mobilization of talent for research in these space-related areas in the medical schools and other research institutions is an important activity of the section on space medical and behavioral sciences.

CELLULAR AND SUBCELLULAR BIOLOGICAL STUDIES

The space biology section is concerned with ground-based fundamental biological studies to be conducted mainly at a cellular and subcellular level. Study of the effects of newly defined extraterrestrial environments on living organisms, assessment of organic chemical and perhaps other life-supporting compounds found in extraterrestrial sites, the development of prototype instruments for identification and analysis of possible extraterrestrial life forms, and prevention of terrestrial contamination of extraterrestrial bodies in order to preserve them for study of remote life or lifelike processes are the principal areas of activity in basic biology.

Ionizing radiation and other components of the electromagnetic spectrum, high vacuum, temperature extremes, and unusual combinations of substances in planetary atmospheres and surfaces as found in extraterrestrial environments provide a new vantage point for observation of the biologic effects on simple organisms, including intimate details of the molecular control of life processes.

Continuation of research and development of effective techniques for sterilization of unmanned spacecraft designed to impact or land on the moon or planets will be supported. Implementation of the acquisition of further information concerning life supporting or related extraterrestrial substances will be augmented. Laboratory simulation of extraterrestrial environments to determine the effects on terrestrial organisms will provide information leading to more productive means of searching for and studying extraterrestrial life forms. Combined with this effort will be laboratory attempts to synthesize primordial molecules to further understanding of the origin of life. These activities will be conducted by molecular biologists, cellular environmental physiologists, and microbiologists in the space biology section.

PURPOSE OF OFFICE OF LIFE SCIENCES

The NASA Office of Life Science Programs has been established to provide a focal point for activities in biology, medicine, and psychology as they relate to the total civilian space effort on a national and international scale. It is the purpose of this office to provide leadership for scientific and technological advances by augmenting desired current programs and by supplying the impetus with proper guidance for further life science contributions in space exploration.

(ADDITIONAL PAPERS ON PROPULSION)

ONE AND A HALF MILLION POUND THRUST ROCKET BOOSTER ENGINE CAPABILITIES

By A. O. Tischler, Chief, Liquid Fuel Rocket Engines Program, NASA

The 1½-million-pound thrust rocket booster engine being developed under contract for NASA by Rocketdyne is a basic booster rocket engine intended for clustering and for upper stage application. The 1½-million-pound thrust booster engine will be used in a cluster of six units in the Nova vehicle to provide a capability of launching very large payloads. With a six-engine booster and a second stage employing an altitude version of the same engine, and with high-energy propellants third and fourth stages, the Nova vehicle will be capable of boosting more than 70,000 pounds into the vicinity of the moon. A payload of this magnitude is required to permit a manned lunar expedition which includes landing on the moon's surface and return to the earth.

ENGINE DESCRIPTION

The thrust and duration of the booster engine were determined by considering the missions expected of the Nova vehicle. Other specifications and design features of the engine were based on a conventional design approach, one which could be supported by the present-day state of art. The engine uses conventional propellants, liquid oxygen, and hydrocarbon fuels. The rocket engine will be developed along lines based on experience gained with the Atlas, Thor, and Saturn engines.

The engine differs from other engines primarily in its physical size, figure 224 shows the throat section of the engine. The entire engine is approximately 20 feet high and has a nozzle diameter of approximately 12 feet. The propellent consumption is nearly 3 tons per second. The turbine which drives the pumps generates approximately 55,000 horsepower and is driven by a separate gas generator which is about the size of some of the rocket engines that have already been developed in other programs.

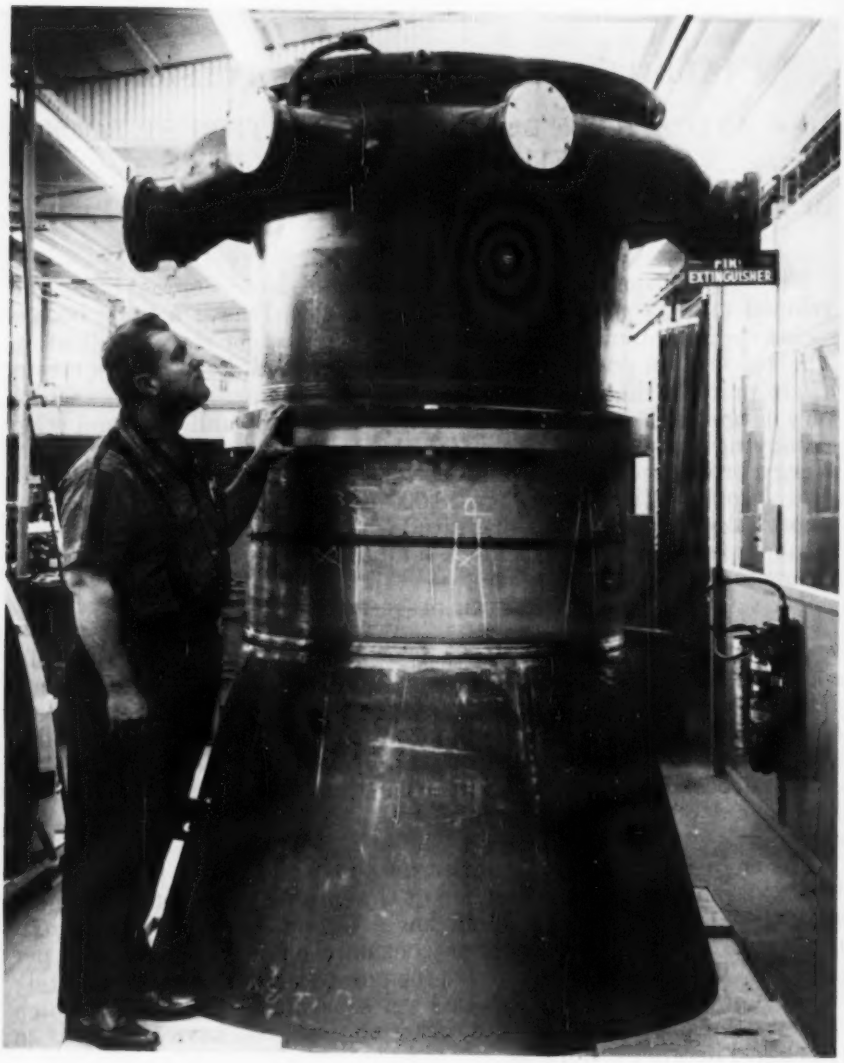


FIGURE 224. Throat section of 1,500,000 pound thrust rocket booster engine.

ENGINE-TEST FACILITIES

Initial tests of the thrust chamber for the 1½-million-pound thrust engine are being conducted on Air Force stands located in the Santa Susana facility operated by Rocketdyne. These facilities are limited in thrust capability and in propellant supply. Accordingly, the duration of thrust chamber tests is limited.

The principal tests of the thrust chamber and of the complete engine will be conducted on facilities at Edwards Air Force Base. These facilities, the layout of which is shown in figure 225, have been furnished by the Air Force which is cooperating to the fullest extent with NASA in the use of these facilities. The first of these stands, stand 2A, was ready for mounting a thrust chamber on July 1, 1960. This stand is primarily for testing of thrust chambers rather than of complete engines. Thrust-chamber testing is expected to be underway on stand 2A at Edwards Air Force Base before the end of July 1960.

HIGH THRUST TEST AREA
EAFB
TEST STAND 1-B
CONTROL CENTER
TEST STAND 2-A
TEST STAND 1-A

FIGURE 225

Two other facilities will also be made available. These will be used for engine testing. One of these is stand 1A, shown in figure 226, which has been converted from an Atlas missile static thrust stand. This stand conversion is expected to be complete early in 1961. The second stand is stand 1B. Stand 1B will be capable of mounting the one and a half million pound thrust engine for full duration tests. This is a new stand built by the Air Force specifically for the one and a half million pound thrust engine project.

PROGRAM STATUS

At the present time design, fabrication, and test work on the engine have been underway approximately a year and a half. During that time the design of the principal components of the engine, the thrust chamber and the turbopump has been completed. The thrust chambers are presently in an advanced stage of fabrication and will be ready for testing on the new stand 2A at Edwards Air Force Base. The turbopump components have also been fabricated and are presently being assembled for testing which will be conducted in the Santa Susana facility beginning in the fall of this year.

Thrust chamber injector testing has been carried out on this program since March 1959. These tests have been made on an interim facility at the Santa Susana location. Tests have been conducted using an uncooled thrust chamber of thick metal built to tolerate the high-temperature high-velocity gas flow for the test time which was limited by the propellent supply. These tests have laid the background for the design of injectors to be used in the long duration regeneratively cooled runs at the Edwards Air Force Base facility.

FIGURE 225

Several factors including a steel strike and the shortage of funds for this project during the 1960 fiscal year, have caused the estimated completion date for the project to slip from January 1963 to mid-1963. This slippage of the project will result in an increase in the total cost of the work. The present contract price is somewhat over $102 million. This is an estimated price based on cost-plus-fixed-fee contract. However the inclusion of approximately $3 million of special equipment items which are required in the conduct of the program and the result of the program slippage are expected to push the contract price to about $110 million. These figures do not include the cost of Government-furnished propellants. The total cost of propellants for this project is of the order of $20 million. Agreements have been made with the Air Force to supply liquid oxygen from Air Force plants for this project. The cost of this oxygen will be considerably less than the cost of procuring oxygen from commercial sources.

NUCLEAR PROPULSION FOR AIR-BREATHING ENGINES

BY WILLIAM H. WOODWARD, CHIEF, POWERPLANTS RESEARCH DIVISION, NASA

The reasons why we want to apply nuclear energy to aircraft are obvious. They are unlimited range and long endurance. The problems that are involved are in many cases unique. Many of them are still unsolved, and all of them are difficult.

When one is talking about nuclear energy for aircraft, one generally is speaking of two categories of application. One, the direct air cycle; and the other, the indirect air or closed heat exchange system.

53795 O—60—pt. 2——27

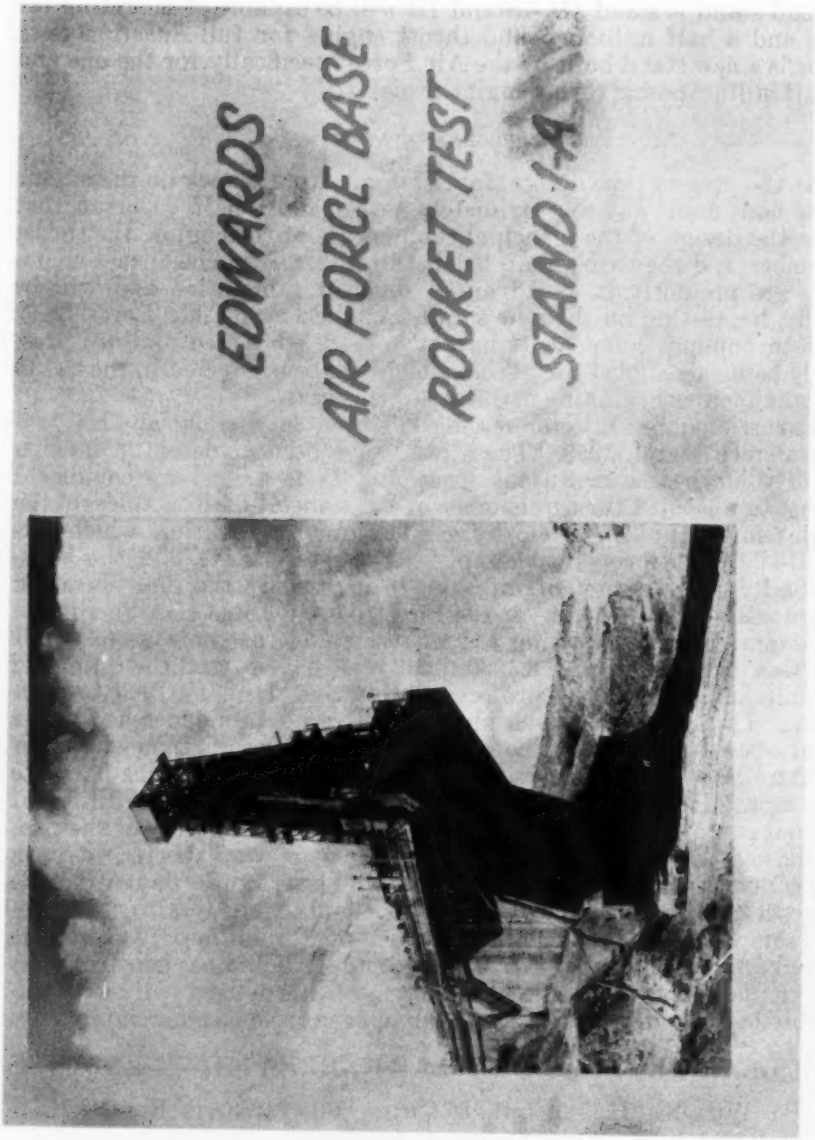


FIGURE 226

DIRECT AIR CYCLE ENGINE

In the direct air cycle, such as illustrated in figure 227, the air comes in the front of a turbojet, and passes directly through the reactor, then through the turbine and on out the exhaust nozzle. Hence the name "direct air cycle." The heat from the nuclear fuel is added to the air by conduction. The nuclear fission takes place within the reactor. The area around the reactor represents the shielding that is required to protect the aircraft and the crew.

INDIRECT CYCLE SYSTEM

In the indirect system or the closed heat exchange system, shown in figure 228, the air that is picked up and fed into the entrance of the turbojet engine does not go through the reactor at all, but through a heat exchanger or radiator and on out the exhaust nozzle. The heat is brought from the reactor into the heat exchanger by means of a closed heat exchange loop.

This is quite similar to a hot water heating system in a house where the combustion takes place in the furnace, and the heat is transferred from there to the rooms by a hot water radiator.

The fluids that we can use in the heat exchanger can be liquids or gases. If they are liquids, because of the temperature levels we want to run, they are usually a metal, like sodium or potassium. Or, one has an option of also using a gas such as helium.

These two systems and the various ways we can apply them both have advantages, and they also have certain disadvantages. For instance, in the direct air cycle, because air is a poor absorber of heat, the reactor has to be fairly large, so that we can get enough heat from the reactor into the air. Since the reactor is large, then the shield is large, and heavy, and this results in a fairly heavy system.

Furthermore, because hot air is coming from the reactor exit at high temperatures, we have to protect the internal parts of the reactor from oxidation or attack by oxygen.

The indirect or the closed heat exchange system can run at lower temperatures. This is because the heat transfer fluid, the liquid metal or the gas that we have in the closed heat exchange loop, is a superior absorber of heat. Consequently, this reactor can be smaller.

If it is smaller, that is to our advantage, because then the shield can be smaller and we have a device that is lighter. There is not a clear gain because we have an extra piece of equipment in a heat exchanger and a pump that has to pump the liquid metal or gas.

Another problem of importance results from the fact that liquid metals attack the structural materials from which the reactor and engine parts are made. This attack by liquid metal can be as disastrous as oxygen attack.

PROBLEM AREAS FOR NUCLEAR PROPULSION SYSTEMS

More specifically, research is being undertaken in the following problem areas:

1. High temperature materials research.
2. Shielding research.
3. Radiation effect on materials.
4. Reactor physics and engineering.
5. Integrated system problems.

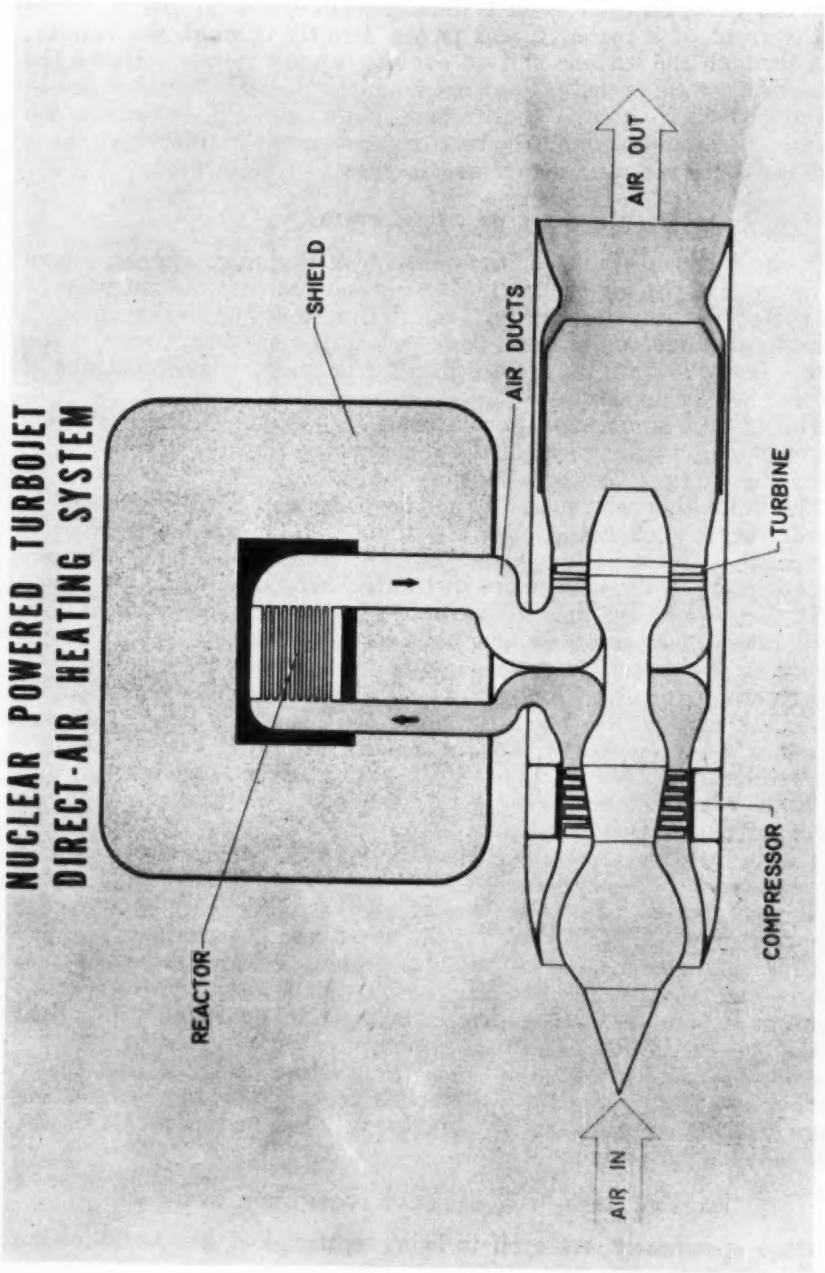

NUCLEAR POWERED TURBOJET
DIRECT-AIR HEATING SYSTEM
SHIELD
AIR DUCTS
AIR OUT
TURBINE
REACTOR
COMPRESSOR
AIR IN

FIGURE 227

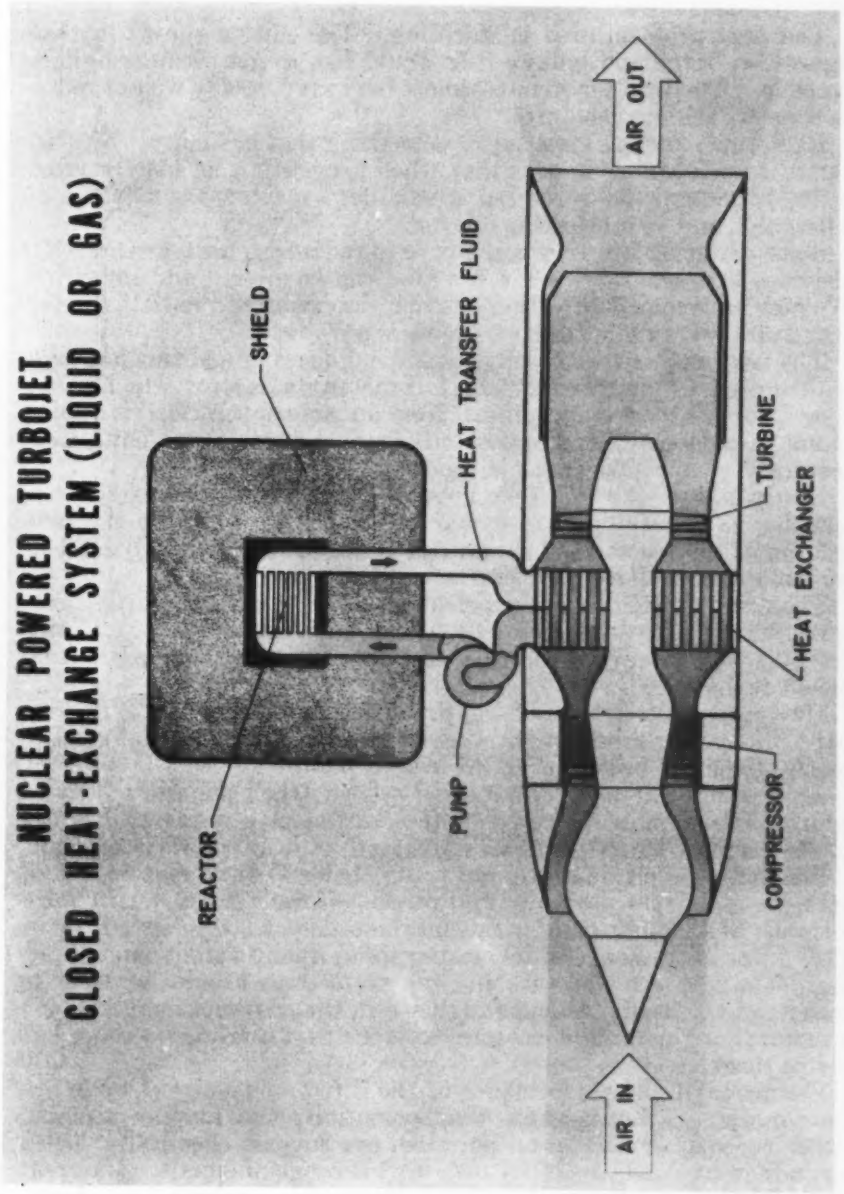

NUCLEAR POWERED TURBOJET
CLOSED HEAT-EXCHANGE SYSTEM (LIQUID OR GAS)
SHIELD
HEAT TRANSFER FLUID
AIR OUT
TURBINE
HEAT EXCHANGER
REACTOR
PUMP
COMPRESSOR
AIR IN

FIGURE 228

The area of high temperature materials reflects the need for materials which can operate at high temperatures in air, or materials that can operate compatibly with a liquid metal or a gas at relatively lower temperatures.

The next problem area is shielding. The shields shown in these figures are large and bulky. We would like to get them as light as possible. The whole system is almost too heavy, so any weight reduction we can achieve is helpful.

Radiation effect on materials is something that has not yet been adverted to. It simply means that when a material, let's say a lubricating oil, is exposed to the radiation from a reactor, one may end up with gunk, and no lubricating oil.

Some materials are very responsive to radiation; some are not. Of the ones that are, there are a few that can be altered and improved. We now have some lubricating oils that can withstand radiation levels that 2 or 3 years ago we did not feel were possible.

The next area is reactor physics and engineering and this has to do with design of the reactor. Unfortunately, a reactor which is designed for the most compactness, from a reactor operation viewpoint, is not always the best design for trying to get the heat out. Consequently, compromises must be made.

Lastly is an area which I am not sure we could call a research problem, but is something that should be mentioned. This in the integration of the reactor and its control systems, and the engine and its control systems, all together into an airplane.

These integrated system problems are perhaps not research problems, but they are time consuming and they have to be started sufficiently well in advance so that all phases of the airplane are completed at the same time.

Having discussed some of the problems, I would now like to compare the nuclear system with some of the more conventional systems to give some perspective as to the overall picture.

I am comparing now an advanced system (the chemically fueled), which has been in existence for quite a while with a system that is just in its infancy, so the comparison should be drawn with some care.

Conventional airplane engines using chemical fuels as a source of energy can carry a payload of 20 percent of their gross weight for a distance of 7,000 miles at speeds on the order of 500 miles per hour. This value decreases with increasing speed due to aerodynamic heating. The airplane structure and engines become heavier in order to withstand the heat. At some high speed, the conventional airplane's structural engine weight becomes so large that there is no room left for payload.

Estimates of the performance of the direct and indirect cycle nuclear-powered aircraft show that potentially the nuclear aircraft, either turbojet or turboprop powered, can surpass chemically fueled aircraft in payload capability over a wide range of speeds. Currrent technology does not yet allow us to achieve this performance. However, current technology will permit the design and construction of a subsonic airplane of substantial payload capability.

APPENDIX

United States and Russian satellites, lunar probes and space probes, 1957 to June 1960

United States and Russian satellites, lunar probes and space probes 1957 to June 1960

(Official statistics prepared by the National Aeronautics and Space Administration [1])

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee[2] (miles)	Apogee[2] (miles)
Sputnik I, Russia: Satellite (sphere). Estimate of total payload weight in orbit: About 4 tons (unofficial). Scientific instrumentation inpayload: 184 lbs.	Oct. 4, 1957, to Jan. 4, 1958.	Not disclosed.....	Dimensions: 22.8 in. in diameter. Experiments: Internal temperatures, pressures, and other data. Shell composition: aluminum alloys. Antennas: 4 spring-loaded whip antennas, 4 ft. 10.5 in. to 9 ft. 6 in. Transmitters: (*a*) 20.005 mc.; (*b*) 40.002 mc. Power supply: Chemical batteries. Transmitter lifetime: (*a*) and (*b*) stopped Oct. 27, 1957.	Period: 96.17 mins.; speed (perigee): 18,000 m.p.h.; speed (apogee): 16,200 m.p.h. Inclination to Equator: 65°.	142	558
Sputnik II, Russia: Satellite (complex). Estimate of total payload weight in orbit: About 4 tons (unofficial). Scientific instrumentation in payload: 1,120 lbs.	Nov. 3, 1957, to Apr. 14, 1958.	.....do.....	Dimensions: Not disclosed. Experiments: Cosmic rays; solar ultraviolet and X-radiation; test animal "Laika" (dog); temperatures; pressures. Shell composition. Aluminum alloys. Antennas: Not disclosed. Transmitters: (*a*) 20.005 mc.; (*b*) 40.002 mc. Power supply: Chemical batteries. Transmitter lifetime: (*a*) and (*b*) stopped Nov. 10, 1957.	The available acceleration of this satellite led to the discovery of significant solar influence on upper atmosphere densities. Period: 103.70 mins.; speed (perigee): 18,000 m.p.h.; speed (apogee): 15,000 m.p.h. Inclination to Equator: 65°.	140	1,038
Vanguard (test vehicle 3) United States: Satellite (sphere). Scientific payload and total weight in flight: 3.25 lbs.	Dec. 6, 1957-0...	U.S. Navy test vehicle 3. Stages: 3—1st: liquid; 2d: liquid; 3d: solid. Gross takeoff weight: 22,600 lbs. Height: 72 ft. Diameter (base): 45 in.	Dimensions: 6 in. in diameter. Experiments: Micrometeor impact and geodetic measurements. Shell composition: Magnesium, aluminum, silicon monoxide. Antennas: 1 turnstile antenna; 1 dipole antenna with total of 6 12-in. rod elements. Transmitters: (*a*) 108 mc. at 10 mw.; (*b*) 108.03 mc. at 5 mw. Power supply: (*a*) mercury batteries; (*b*) 6 groups of solar converters.	Vehicle lost thrust after 2 secs. and was consumed in flames. Cause: malfunction in 1st stage.	0	0
Explorer I, United States: Satellite (cylinder). Total payload weight in orbit, 30.8 lbs. Scientific instrumentation in payload, 18.13 lbs.	Jan. 31, 1958 (estimated lifetime: 3 to 5 yrs.).	U.S. Army Jupiter C: Stages: 4—1st, elongated Redstone (liquid); 2d, scaled-down Sergeant rockets (solid); 3d, scaled-down Sergeant rockets (solid); 4th, single scaled-down Sergeant (solid). Height: 68.6 ft.	Dimensions: 80 in. long; 6 in. in diameter. Experiments: cosmic rays; micrometeorites: (*a*) microphone; (*b*) gages; temperatures: internal, rear skin, front skin, and nose cone. Shell composition: Steel with 8 aluminum oxide strips. Antennas: 1 turnstile antenna with 4 whip elements each 22.5 in. long; 1 dipole antenna using skin of satellite itself. Transmitters: (*a*) 108 mc. at 10 mw. and (*b*) 108.03 mc. at 60 mw. Power supply: Mercury batteries. Transmitter lifetime: (*a*) stopped May 23, 1958; (*b*) stopped Feb. 11, 1958; began again Feb. 24; stopped finally Feb. 28, 1958.	Explorer I is credited with what is probably the most important satellite discovery of the International Geophysical Year; i.e., a radiation belt around the Earth identified by Dr. James A. Van Allen, head of the University of Iowa Physics Department. A 2d belt was discovered later by Pioneer III. Period: 114.8 mins. Inclination to Equator: 33.34°.	224	1,573

Vanguard: (test vehicle 3 backup) United States: same as TV 3.	Feb. 5, 1958-0...	Same as Vanguard test vehicle 3.	Same as Vanguard test vehicle 3.....	After a successful liftoff and 57 sec. of flight, a connection between units of 1st stage control system failed to function. At an altitude of 20,000 ft., the rocket veered off course with such force that it snapped apart and fell.	0	0
Explorer II, United States: Satellite (cylinder). Total payload weight in orbit, 31.50 lbs. Scientific instrumentation payload, 18.83 lbs.	Mar. 5, 1958-0...	U.S. Army Jupiter C (same as Explorer I).	Dimensions: 80 in. long; 6 in. in diameter. Experiments: Cosmic ray count; micrometeor impact count; cosmic ray measurement. Shell composition: No. 410 stainless steel. Antennas: 2 dipole antennas using skin of satellite itself. Transmitters: (a) 108.03 mc. at 60 mw.; (b) 108.00 mc. at 10 mw. Power supply: Mercury batteries.	Last stage failed to ignite. Vehicle did not achieve orbit. Flight time: 823 sec.	0	0
Vanguard I, United States: Satellite (sphere). Scientific payload and total weight in orbit, 3.25 lbs. (Also in orbit, 50-lb. 3d stage rocket casing.)	Mar. 17, 1958 (estimated 200 to 1,000 yrs.).	Same as test vehicle 3.	Dimensions: 6.4 in. in diameter. Experiments: Temperatures and geodetic measurements. Shell composition: Aluminum. Antennas: one turnstile antenna and one dipole antenna with total of six 12-in. rod elements. Transmitters: (a) 108 mc. at 10 mw.; (b) 108.03 mc. at 5 mw. Power supply: (a) Mercury batteries; (b) 6 groups of solar converters. Transmitter lifetime: (a) Ceased operating Apr. 5, 1958; (b) will operate indefinitely.	The solar-powered radio should transmit indefinitely. The Army Map Service has been making electronic observations of the satellite from Pacific islands to pinpoint their location more exactly. The satellite is also being used for more exact determination of the Earth's shape.	409	2,453
Explorer III, United States: Satellite (cylinder). Total payload weight in orbit, 31 lbs. Scientific instrumentation payload, 18.56 lbs.	Mar. 26, 1958 (June 27, 1958).	U.S. Army Jupiter C (same as Explorers I and II).	Dimensions: 80 in. long; 6 in. in diameter. Experiments: Cosmic rays with tape-recorder feature; micrometeor gages; temperatures, (a) skin and (b) internal. Shell composition: Steel with 8 aluminum oxide strips. Antennas: 2 dipole antennas using skin of satellite itself. Transmitters: (a) 108 mc. at 10 mw.; (b) 108.03 mc. at 60 mw. Power supply: Mercury batteries. Transmitter lifetime: (a) Telemetering and beacon signal stopped May 10, 1958; beacon transmitted again May 15-June 16; (b) first stopped May 14; responded erratically May 22-June 5, 1958.	Explorer yielded valuable data on the radiation belt discovered by Explorer I as well as data on micrometeor impacts (density of cosmic dust) and internal and external temperature of the satellite. Period: 115.87 min. Inclination: 33.4°.	121	1,746
Vanguard (test vehicle 5): Satellite (sphere). Scientific payload and total weight in orbit, 21.5 lbs.	Apr. 28, 1958-0...	Same as TV 3.....	Dimensions: 20 in. in diameter. Experiments: Measure X-radiation from the sun. Shell composition: Highly polished silicon-monoxide-coated magnesium. Antennas: 4 metal rods. Transmitters: (a) 108 mc. at 10 mw.; (b) 108.03 mc. at 5 mw. Power supply: Mercury batteries.	2 minor components (electric relays) malfunctioned and failed to signal the 3d stage to fire. 2d and 3d stages impacted 1,500 miles from launch site.	0	0

See footnotes at end of table, p. 1006.

United States and Russian satellites, lunar probes and space probes 1957 to June 1960—Continued

(Official statistics prepared by the National Aeronautics and Space Administration [1])—Continued

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee[2] (miles)	Apogee[2] (miles)
Sputnik III, Russia: Satellite (conical). Total payload weight in orbit: About 7,000 lbs. (unofficial). Scientific instrumentation payload, 2,925 lbs.	May 15, 1958, to Apr. 6, 1960.	Not disclosed	Dimensions: 11 ft. 9 in. long; 5 ft. 8 in. wide at base. Experiments: Atmospheric pressure and composition; concentration of positive ions; satellite's electrical charge and tension of earth electrostatic field; tension of earth's magnetic field; intensity of sun's corpuscular radiation; composition and variations of primary cosmic radiation; distribution of photons and heavy nuclei in cosmic rays; micrometeors; temperature measurements. Shell composition: Aluminum alloys. Antennas: Folded dipole antennas and trailing rod antennas. Transmitters: (*a*) 20.005 mc. (transmission at 40.01 mc. is harmonic of 1st) Power supply: (*a*) chemical batteries; (*b*) solar batteries.	Period: 106 min.; speed (perigee): 18,837; speed (apogee): 14,637. Inclination to Equator: 65.3°.	135	1,167
Vanguard, satellite launching vehicle 1 (no name), United States: Satellite (sphere). Scientific payload and total weight in orbit: 21.5 lbs.	May 27, 1958-0..	Same as TV 3	Dimensions: 20 in. in diameter. Experiments: Solar Lyman-Alpha radiation and space environment. Shell composition: Highly polished silicon monoxide coated magnesium sphere. Antennas: 4 metal rods. Transmitter: (*a*) 108 mc. at 10mw.; (*b*) 108.03 mc. at 5 mw. Power supply: (*a*) Mercury batteries; (*b*) 6 groups of solar converters. Transmitter lifetime: same as flight time; i.e. 20 min.	Second stage engine did not cut off properly, causing vehicle to fly with nose upward rather than parallel to earth. Caused 3d stage to fly in high arc-like trajectory. 3d stage of satellite reached peak altitude of 2,200 miles and traveled 7,500 miles from Cape Canaveral, landing near east coast of Union of South Africa. Flight time: 20 min.	0	0
Vanguard (SLV 2) (no name), United States: Satellite (sphere). Scientific instrumentation in payload and total weight in orbit: 21.5 lbs.	June 26, 1958-0..	....do....	Dimensions: 20 in. in diameter. Experiments: Measurements of X-radiation from the sun. Shell composition: Highly polished silicon monoxide magnesium sphere. Antennas: 4 metal rods. Transmitters: (*a*) 108 mc. at 10 mw.; (*b*) 108.03 mc. at 5 mw. Power supply: (*a*) mercury batteries; (*b*) 6 groups of solar converters.	Second stage motor cut off prematurely due to low chamber pressure and terminated the flight.	0	0

Explorer IV, United States: Satellite (cylinder). Total payload weight in orbit: 38.4 lbs. Scientific instrumentation in payload: 25.8 lbs.	July 26, 1958, to Oct. 22, 1959.	Same as Explorer I....	Dimensions: 80.39 in. long; 6.25 in. in diameter. Experiments: 2 Geiger-Mueller counters and 2 scintillation counters to measure corpuscular radiation at several intensity levels. The subcarrier oscillator was calibrated to give internal temperature measurements. Shell composition: stainless steel. Antennas: 2 dipole antennas using the skin of the satellite itself. Transmitters: (a) 108 mc. at 10 mw.; (b) 108.03 mc. at 24 mw. (each transmitter broadcasts all 5 channels of information simultaneously and continuously. The 1st transmitter is primarily for tracking.) Power supply: Mercury batteries. Transmitters lifetime: Sept. 3, 1958: Telemetry on channels 2 and 5 cease. Sept 9, 1958: 108.00 mc. transmitter ceased operation Sept. 19, 1958: Last intelligible telemetry on 108.03 mc. transmitters. Oct. 6, 1958: 108.03 mc. transmitter ceased.	Same as Explorer I and III, i.e. valuable data on radiation belts, etc. Period: 110.27 min. Inclination to Equator: 50.29°.	163	1,380
No name, United States: Lunar probe (toroidal). Total payload weight in flight, including 4th stage shell: 83.8 lbs. Scientific instrumentation in payload: 25 lbs.	Aug. 17, 1958-0..	Thor-Able I Stages: 4. 1st: Thor (liquid); 2d: Modified Vanguard. 2d stage (liquid); 3d: X2 Allegany Ballistic Laboratory (solid); 4th Thiokol (solid). Gross take-off weight: 112,000 lbs.; height: 88.1 ft.	Dimensions: 29 in. in diameter; 30 in. long. Experiments: Measurements of radiation in space; magnetic fields of Earth and Moon; density of micormeteoric matter; internal temperatures; electronic scanner. Shell composition: Fiberglass. Antennas: Two 12-inch whips. Transmitters: (a) 108.6 mc. at 300 mw. (telemetry and doppler command); (b) 108.09 mc. at 1 watt. Power supply: Mercury batteries. Transmitter lifetime: 10 days.	Engine failure in 1st stage caused vehicle blow up 77 seconds after launch.	(3)	(3)
Explorer V, United States: Satellite (cylinder). Total payload weight in orbit: 38.43 lbs. Scientific instrumentation in payload: 25.8 lbs.	Aug. 24, 1958-0..	Jupiter C.....	Dimensions: 80 in. long, 6 in. in diameter. Experiments: measurement of corpuscular radiation at several intensity levels. Shell composition: No. 410 stainless steel. Antennas: 2 dipole antennas using skin of satellite itself. Transmitters: (a) 108.03 mc. at 30 mw.; (b) 108.00 mc. at 10 mw. Power supply: Mercury batteries.	Successful launching. All stages fired. Orbit was not achieved because of a collision between parts of the booster and the instrument compartment which carried the 3 high-speed stages. The high-speed stages fired in wrong direction. Flight time: 659 seconds.	0	0
Vanguard (SLV 3) United States: Satellite (sphere). Scientific instrumentation in payload and total weight, 21.5 lbs.	Sept 26, 1958-0...	Same as TV 3.....	Dimensions: 20 in. in diameter. Experiments: 2 infrared photocells to scan earth's cloud cover. Shell composition: Magnesium. Antennas: 1 turnstile antenna with 4 30-in. spring-loaded rod elements. Transmitters: 108.00 mc. at 10 mw. and 108.03 mc. at 1 watt. Power supply: Mercury batteries.	2d stage failed to give minimal performance, which caused vehicle to fall back into atmosphere and burn up. It is believed to have made 1 complete orbit of Earth before falling back and burning up over central Africa.	0	0

See footnotes at end of table, p. 1006.

United States and Russian satellites, lunar probes and space probes 1957 to June 1960—Continued

(Official statistics prepared by the National Aeronautics and Space Administration [1])—Continued

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee[2] (miles)	Apogee[2] (miles)
Pioneer I, United States: Lunar probe (toroidal). Total weight in flight, 84.4 lbs., including 43.7 lbs. of verniers and retrorockets. Scientific instrumentation in payload, 39 lbs.	Oct. 11–12, 1958, or 43 hrs. 17½ min.	Thor-Able I	Dimensions: 29 in. in diameter, 30 in. long. Experiments: Measurements of radiation in space; magnetic fields of Earth and Moon; density of micrometeor matter; internal temperatures; electronic scanner. Shell composition: Fiberglass. Antennas: 2 12-in. whips. Transmitter: (*a*) 108.06 mc. at 300 mw. (telemetry and Doppler command); (*b*) 108.06 mc. at 1 watt (controls). Power supply: Mercury batteries. Transmitter lifetime: 10 days.	Reentered atmosphere over South Pacific Oct. 12, 1958. (*a*) Determination of radial extent of radiation band. First observation that radiation is a band. (*b*) Mapped total ionizing flux. (*c*) 1st observation of hydromagnetic oscillations of magnetic field of Earth. (*d*) Discovered departure of magnetic field from theoretical prediction. (*e*) 1st determination of the density of micrometeors in interplanetary space. (*f*) 1st measurements of the interplanetary magnetic field.	(4)	(4)
Beacon, United States: Inflatable satellite (sphere). Payload case, 18.3 lbs.; rocket case, 11.27 lbs.; total, 31.5 lbs. Weight of inflatable satellite when free of payload case, 9.26 lbs.	Oct. 23, 1958–0	Jupiter C	Dimensions: 50 in. long, 7 in. in diameter; contained the foiled sphere, tracking transmitter, kick motor, and pressurized bottle. Experiments: Ejection of sphere from payload package; sphere itself would be used to study atmospheric density at various levels during lifetime of about 2 weeks. Shell composition: Mylar polyester film and microthin aluminum foil. Transmitters: None.	Part of the cluster, including payload, separated from the booster prior to booster burnout. Flight time of payload, 424 sec. Flight time of booster, 526 sec.	0	0
Pioneer II, United States: Lunar probe (toroidal). Total weight in flight, 86.4 lbs. Scientific payload, 34.3 lbs.	Nov. 8, 1958, 42.4 min.	Thor-Able I	Dimensions: 29 in. in diameter; 30 in. long. Experiments: Total ionizing radiation; cosmic ray flux; magnetic fields of Earth and Moon; density of micrometeoric matter; internal temperatures; electronic scanner. Shell composition: Fiberglass. Antennas: 2 12-in. whips. Transmitters: 108.06 mc. at 300 mw. (telemetry and Doppler command) and 108.09 mc. at 100 mw. (telemetry). Power supply: Mercury batteries. Transmitter lifetime: 10 days.	3d stage failed to ignite. Reentered atmosphere 28.7° N., 1.9° E. (*a*) Evidence that equatorial region about Earth has higher flux and higher energy radiation than previously considered. (*b*) Suggestion that micrometeor density is higher around Earth than in space.	(4)	(4)
Pioneer III, United States: Space probe (conical). Total weight in flight and scientific payload, 12.95 lbs.	Dec. 6–7, 1958, or 38 hrs., 6 min. after launch.	Juno II stages (4): 1st, Jupiter (liquid); 2d, 11 clustered Sergeants (solid); 3d, 3 clustered Sergeants (solid). Gross takeoff weight, 121,000 lbs. Launch vehicle 76 ft. high, 8¾ ft. in diameter.	Dimensions: 23 in. long; 10 in. maximum diameter. Experiments: Measurement of radiation in space. Shell composition: Gold-washed Fiberglass. Antenna: Cone itself serves as antenna; gold is conductor. Transmitters: 960.05 mc. at 180 mw. Power supply: Mercury batteries. Transmitter lifetime: 90 hrs.	Discovered 2d radiation belt around Earth. Reentered atmosphere over French Equatorial Africa on Dec. 7, 1958. Designed velocity, 24,897 m.p.h. Attained velocity, about 24,000 m.p.h.	(4)	(4)

Project Score (Atlas), United States: Satellite. Total weight in orbit, 8,750 lbs. Scientific instrumentation in payload, 150 lbs.	Dec. 18, 1958–Jan. 21, 1959.	WS107A–1 (Atlas): Powerplant, 2 boosters (approximately 150,000 lbs. each) and 1 sustainer engine (all liquid) plus 2 verniers. Gross takeoff weight, about 244,000 lbs. Height, 85 ft. Diameter, 10 ft.	Dimensions: 85 ft. long, 10 ft. in diameter. Experiments: Twin packages of radio transmitting, recording, and receiving apparatus, each weighing 35 lbs. Other components included a battery, a voltage converter, radio beacon, and a control unit. Shell composition: Stainless steel. Antennas: Slot-type, flush with body of the Atlas. Transmitters: FM, 132.435 mc. and 132.905 mc. Minitrack signals: 107.97 mc. and 107.94 mc. Power supply: Mercury batteries. Transmitter lifetime: 12 days.	1st time a human voice has been beamed from outer space. Message from President Eisenhower recorded and transmitted. Satellite accepted and relayed messages from ground stations in Texas, Arizona, and Georgia. It came down in vicinity of Midway Island in Pacific Ocean. Initial period, 101.46 min. Inclination, 32.3°.	110	920
Lunik or Mechta (Dream), Russia: Space probe (sphere). Total weight in flight, 3,245 lbs.[7]	Jan. 2, 1959 (believed to be in orbit around Sun).	T–3 stages: 3. Speculated total thrusts, 580,000 lbs. Height, 110 ft.	Dimensions: Not disclosed. Experiments: Instruments to measure temperature and pressure inside vehicle; instruments to study gas components of interplanetary matter and corpuscular radiation of the Sun; magnetic fields of Earth Moon; meteoric particles in space; heavy nuclei in primary cosmic radiation and other properties of cosmic rays. Shell composition: Pentagonal strips of stainless steel made of 2 hermetically sealed shells of aluminum-magnesium alloy. Antennas: Not disclosed. Transmitters: 3. (*a*) 19.997 mc. and 19.995 mc. signals of 1.6-sec. duration; (*b*) 19.993 mc. signals of 50.9-sec. duration; (*c*) 183.6 mc.	In orbit around Sun on 15-mo. cycle.	----------	------
Vanguard II, United States (sphere): Total weight in orbit and scientific instrumentation, 20.5 lbs.	Feb. 17, 1959. Expected lifetime, 10 yrs. or more.	SLV 4	Dimensions: 20 in. in diameter. Experiments: Cloud cover. Shell composition: Highly polished silicon monoxide coated magensium. Antennas: 4 metal rods. Transmitters: (*a*) 108 mc. at 10 mw.; (*b*) 108.03 mc. at 1 watt triggered from ground. Power supply: Mercury batteries. Transmitter lifetime: (*a*) 23 days; (*b*) 27 days. Satellite contained 2 infrared photocells designed to produce crude images of cloud cover for 2-week period.	Period: 125.85 min. Inclination to Equator: 32.88°. In general the satellite and its instrumentation functioned as planned. However, interpretation of cloud cover data has been difficult because satellite developed a wobbling (precessing) motion. Velocity: 18,299 m.p.h. at perigee; 13,109 m.p.h. at apogee.	350	2,055

See footnotes at end of table.

United States and Russian satellites, lunar probes and space probes 1957 to June 1960—Continued

(Official statistics prepared by the National Aeronautics and Space Administration [1])—Continued

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee[2] (miles)	Apogee (miles)[2]
Discoverer I, United States: Satellite (cylinder). Total weight of satellite, 1,300 lbs., including 245 lbs. of instruments. Launched from Vandenberg AFB, Calif., into polar orbit.	Feb. 28 to early Mar., 1959.	Thor-Hustler Standard Thor booster with a 2d stage designed to go into orbit. Both liquid fueled. Weight, about 108,400 lbs. Height, 78.6 ft.	Dimensions: Length 19.2 ft., diameter 5 ft. Objectives: Check out propulsion, guidance, staging, communications. Antennas: 1 directional and 1 whip antenna. Transmitters; classified but included telemetry and tracking beacon, Power supply: Nickel-cadmium batteries.	Period: 95.57 mins. Difficulty in stabilization caused tumbling which hampered consistent tracking acquisition. After about 5 days, it is presumed from tracking reports the satellite burned up on reentry into atmosphere at an unknown point. Inclination: 3° off north-south axis of Earth.	176	519
Pioneer IV, United States (conical): Total weight in flight and scientific instrumentation, 13.40 lbs.	March 3, 1959. In eternal orbit around Sun.	Juno II (same as Pioneer III).	Dimensions: 20 in. long; 9 in. in diameter. Experiments: Measurement of radiation in space. Test photoelectric sensor in vicinity of Moon. Shell composition: Gold-washed fiberglass. Antenna: Cone itself serves as antenna; gold is conductor. Transmitter: 960.05 mc. at 180 mw. with 3 subcarriers. Power supply: Mercury batteries. Transmitter lifetime: About 90 hrs.	Probe achieved its primary mission, an Earth-Moon trajectory, yielded excellent radiation data and provided a valuable tracking exercise. It is now orbiting the Sun. While the probe reached the vicinity of the Moon, it did not come close enough (20,000 miles) to trigger photoelectric sensor or sample Moon's radiation. The probe passed within 37,300 miles of Moon at 5:24 p.m. on Mar. 4, 1959. It passed 7.2° east and 5.7° south of Moon at 4,490 m.p.h. Probe reached perihelion, 91,700,000 miles, at 9 p.m. Mar. 17, 1959; scheduled to reach aphelion, 106,100,000 miles on Oct. 1, 1959. Injection velocity of 24,790 m.p.h. was 188 m.p.h. below planned velocity. Pioneer IV was tracked for 82 hrs. to distance of 407,000 miles.	------	------
				Period: 90.5 mins. All equip-	150	225

Discoverer II, United States: Satellite (cylinder). Total weight, 1,610 lbs., including 245 lbs. of communications and performance instrumentation and a 195-lb. capsule. Launched from Vandenberg AFB, Calif., into polar orbit.	Apr. 13 to 26, 1959.	Thor-Hustler (same as Discoverer I).	Dimensions: 2d stage same as Discoverer I but with a 195-lb. recovery hemisphere-shaped capsule measuring 33 in. in diameter by 27 in. deep. Capsule used small retrorocket to aid reentry. Experiments: To recover capsule; maintain temperature and oxygen sufficient to sustain life; emulsion packs to measure radiation. Antennas: 1 directional and 1 whip antenna. Transmitters: Classified but included telemetry and tracking beacon plus a tracking beacon in recovery capsule. Power supply: Nickel-cadmium batteries. Transmitter lifetime: Telemetry ran to Apr. 14 as planned; tracking beacon ran until Apr. 21 as planned. Capsule composition: Classified.	Period: 90.5 mins. All equipment worked as programed except timer which ejected capsule. Timer difficulty made capsule impact in vicinity of Spitzbergen Islands Apr. 14 instead of Hawaii vicinity where it was to be recovered either by airplane or ship. Capsule, which contained radiation emulsion packs, has not been found. Temperature-oxygen instruments showed life could be supported. Inclination: 0.2° off north-south axis of Earth.	150	225
Vanguard, United States: 2 satellites. Total weight of scientific payloads, 23.3 lbs.	Apr. 13, 1959–0..	Vanguard SLV 5 (same as TV 3).	Dimensions: Vanguard 3A—13-in. ball with 17½-by 2½-in. cylinder extending from it. Vanguard 3B—a 30-in. inflatable sphere containing no instrumentation to be tracked optically. Experiments: Vanguard 3A contained a precise magnetometer to be used to map Earth's magnetic field. Vanguard 3B was to measure drag in space. Composition: 3A was made of fiberglass and phenolic resins. 3B was laminated aluminum foil and plastic sheet. Transmitters: For 3A—108 mc. at 10 mw. for tracking and 108.03 mc. at 80 mw. for telemetry on ground command. Power supply: Silver-zinc batteries. Antennas: 4 spring-lock rods.	2d stage failed to operate properly which caused a tumbling motion. Payload and 3d stage fell into Atlantic Ocean several hundred miles off Cape Canaveral. Total flight time, about 500 sec.	0	0

See footnotes at end of table.

United States and Russian satellites, lunar probes and space probes 1957 to June 1960—Continued

(Official statistics prepared by the National Aeronautics and Space Administration [1])—Continued

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee[2] (miles)	Apogee[2] (miles)
Discoverer III, United States: Satellite and nose cone reentry capsule. Scientific payload and total weight in orbit, 1,600 lbs. (entire 2d stage goes into orbit) including 440-lb. payload, 245 lbs. of which include communications, telemetry, and performance-measuring instrumentation, plus 195-lb. reentry capsule containing 4 black mice. Launched from Vandenberg AFB, Calif.	June 3, 1959-0...	Thor-Hustler stages (2): 1st, Standard Thor modified to accommodate Discoverer III; 2d, Lockheed (designed to go into orbit). Gross takeoff weight, 8,400 lbs.; height, 75.9 ft.; diameter (base), 5 ft.	Dimensions: Recovery capsule is 27 in. long, 33 in. in diameter, containing environmental equipment; 2d stage, all of which goes into orbit, is same as Discoverer I. Experiments: Measurement of cosmic radiation, biomedical environmental research, and capsule recovery techniques by C–119 aircraft patroling recovery area. Antennas: 1 directional and 1 whip antenna. Transmitters: Classified. Power supply: Nickel cadmium batteries.	Preliminary telemetry indicated 2d stage fired. Tracking stations did not receive telemetry from satellite; doubtful it achieved orbit. Injected downward instead of horizontally as programed.	0	0
Vanguard (SLV–6): Satellite (sphere). Total weight in flight and scientific instrumentations, 22.5 lbs.	June 22, 1959-0..	Standard Vanguard SLV.	Dimensions: 20 in. in diameter. Experiments: Measurements of solar-earth heating process which generates weather. Shell composition: Magnesium alloy. Antennas: 4 metal rods. Transmitters: (*a*) 108 mc. at 10 mw.; (*b*) 108.03 mc. at 100 mw. Power supply: Mercury batteries.	A faulty 2d stage pressure valve caused failure. A regulator designed to control helium flow, which drives 2d stage propellants into engine, did not respond to command. Pressure then built up within helium reservoir which ruptured about 40 sec. after 2d stage ignition. Without sufficient pressure on the propellants, 2d stage engine ran roughly. Helium tank burst when vehicle was at 40 to 50 miles altitude. The rocket rolled over in a ballistic trajectory at an altitude of about 90 miles. 3d stage ignited before plunging into Atlantic Ocean some 300 miles northeast of Atlantic Missile Range.	0	0
Discoverer IV, United States: Satellite and nose cone reentry capsule. Scientific payload and total weight in orbit, 1,700 lbs. (entire 2d stage goes into orbit) including 300-lb. reentry capsule.	June 25, 1959-0..	Same as Discover III.	Capsule contained telemetry equipment to measure its performance.	Failed to achieve orbit. Telemetry reports indicate that 2d stage fired. Satellite was not acquired by tracking stations on its 1st or subsequent orbits. Insufficient velocity caused failure to orbit.	0	0

Explorer, United States: Satellite (2 truncated cones joined at bases). Total weight in flight and scientific payload, 91.5 lbs.	July 16, 1959–0	Juno II (Am–16). Same as Pioneer III.	Dimensions: 36 in. high, 30 in. diameter. Experiments: Measurements of (1) earth's radiation balance, (2) Lyman-alpha X-rays, (3) heavy primary cosmic rays, (4) micrometeorites, (5) cosmic rays, (6) satellite temperature, and (7) erosion study of exposed solar (silicon) cell on outside of satellite. Transmitters: (*a*) 20 mc. at 600 mw. on solar power; (*b*) 108 mc. at 15 mw.; power supply: (*a*) solar energy, (*b*) chemical batteries. Transmitter lifetime: (*a*) Cutoff after 1 year; (*b*) 2 months.	Vehicle was destroyed by range safety officer after 5½ secs. when it tilted sharply due to failure of power supply to guidance system.	0	0
Explorer VI, United States: Satellite (paddlewheel; spheroid shaped with flattened bottom plus 4 solar vanes or paddles). Scientific payload and total weight in orbit, 142 lbs.	Aug. 7, 1959. Over 1 yr.	Thor-Able III stages: 1st, Thor (liquid) minus guidance; 2d, Modified Vanguard 2d step (liquid); 3d, X–248 solid rocket made for Vanguard program. Gross takeoff weight, 105,000 lbs. plus; height, 90 ft.	Dimensions: 26 in. in diameter and 29 in. deep with 4 solar vanes 18- by 18-in. square. Experiments: (1) Measurement of 3 specific radiation levels of Earth radiation belt; (2) TV-like scanning device to relay cloud cover picture; (3) solar cells (8,000 in all; 1,000 on each side of 4 paddles) to create voltage to recharge the satellite's chemical batteries in flight (electronic gear in satellite includes 3 transmitters and 2 receivers); (4) micrometeorite detector; (5) 2 types of magnetometer to map Earth's magnetic field; (6) 4 experiments to study behavior of radio waves, all aimed at learning more about deep space communications. Antennas: 2 dipole aluminum rods. Transmitters: (*a*) 108.06 mc. at 500 mw.; (*b*) 108.09 mc. at 500 mw.; (*c*) ultrahigh frequency (undisclosed). Power supply: Nickel-cadmium batteries rechargeable by 8,000 solar cells mounted on 20- by 22-in. vanes jutting from satellite's equator.	Experiment successful even though 1 "paddle" failed to function properly. Valuable data transmitted on distribution of dust particles and concentration of low-energy particles. Period, 12½ hrs.; speed (perigee), 23,031 m.p.h.; speed (apogee), 3,126 m.p.h. Inclination to equator, 46.9°.	156	26,357
Discoverer V, United States: Satellite and nose cone reentry capsule. Total weight, approximately 1,700 lbs. (entire 2d stage) including 300-lb. reentry capsule. Launched from Vandenberg AFB, Calif., into polar orbit.	Aug. 13, 1959. Rocket carrier down Sept. 28, 1959.	Thor-Agena stages (2): 1st, standard Thor; 2d, Agena.	Same as Discoverer IV	Satellite went into orbit, all equipment working as programed. However, reentry capsule was not recovered due to malfunction following its ejection from satellite. Period, 94 mins. In February 1960 it was determined that a so-called mystery satellite was, in reality, the intended reentry capsule of Discoverer V. Apparently, the retrorocket had fired at an incorrect angle, kicking the capsule into a higher orbit instead of slowing it down for reentry.	136	450

See footnotes at end of table.

United States and Russian satellites, lunar probes and space probes 1957 to June 1960—Continued

(Official statistics prepared by the National Aeronautics and Space Administration [1])—Continued

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee[2] (miles)	Apogee[2] (miles)
Beacon, United States: Satellite (sphere). Scientific instrumentation in 3d-stage rocket casing 25.8 lbs., including 10-lb. inflatable sphere which is ejected to fly into orbit free of payload case. Total weight in orbit including spent 3d stage, 84 lbs.	Aug. 14, 1959–0..	Modified Juno II (AM–19B) stages (3): 1st, Jupiter (liquid); 2d, 11 clustered Sergeants (solid); 3d, 3 clustered Sergeants (solid). Gross takeoff weight, 121,000 lbs.	Dimensions: 7 by 31½ in. (inflatable sphere is 12 ft. in diameter when inflated). Experiments: Inflatable satellite of Mylar plastic film and aluminum foil. Satellite itself contains no instrumentation. Ejection and inflation mechanism consists of nitrogen bottle, a bellows, a piston, and a connecting valve. Shell composition: Stainless steel. Transmitter: 108.03 mc. at 50 mw. (in rocket casing). Power supply: 12 mercury batteries.	Payload failed to achieve orbit due to premature fuel depletion in booster and malfunction in attitude control system for upper stages. Time to 3d-stage burnout (normally time of injection into orbit), 11.07 mins.	0	0
Discoverer VI, United States: Satellite and nose cone reentry capsule. Total weight, approximately 1,700 lbs. (entire 2d stage) including 300-lb. reentry capsule. Launched from Vandenberg AFB, Calif., into polar orbit.	Aug. 19, 1959. Oct. 20, 1959.	Same as Discoverer V.	Same as Discoverer IV	Same as Discoverer V	139	537
"Lunik II." Russia: Lunar probe (hermetically sealed sphere). Estimate of total payload weight: 858.4 lbs.[7]	Launched 6 a.m. e.d.t. (estimated) on Sept. 12, 1959. Time of impact on the Moon: 5–02:24 p.m.e.d.t. on Sept. 13, 1959.	Multistage rocket. Weight of 2d stage minus fuel: 3,324 lbs. Other details undisclosed.	Dimensions: not given. Experiments: Instruments to measure temperature and pressure inside vehicle; instruments to study magnetic fields of Earth and Moon; meteoric particles in space; heavy nuclei in primary cosmic radiation and other properties of cosmic rays. Shell composition: Pentagonal strips of stainless steel made of two hermetically sealed shells of aluminum-magnesium alloy. Antennas: Not disclosed. Transmitters: (*a*) 183.6 mc. (altimeter in probe); (*b*) 39.986 mc. (in probe); (*c*) 19.993 mc. (in probe); (*d*) 20.003 mc. (in rocket); (*e*) 19.997 mc. (in rocket).	58.4-lb. lunar probe hit surface of the Moon at 5:02:24 p.m. e.d.t. 1 min. 24 sec. later than predicted by Russia scientists; total flight time: about 35 hrs. (The probe contained scientific instruments and the Soviet coat of arms.) When it hit the Moon, the container was traveling more than 2 miles per second. (Expended final stage also hit the Moon.)	Distance traveled, 236,875 miles.	
Transit I–A. United States: Satellite (sphere). Total weight in flight and scientific payload: 265 lbs.	Sept. 17, 1959–0..	Standard 3-stage Thor-Able.	Dimensions: 36 in. in diameter. Shell composition: 2 layers fiber glass with honeycomb structure in between. Antennas: Broad band spiral antenna painted on outside of shell. Transmitters: (*a*) 54 mc.; (*b*) 162 mc.; (*c*) 216 mc.; all at 100 mw. Power supply: 2 silver zinc; 2 nickel-cadmium; latter 2 powered by solar cells.	Satellite failed to achieve orbit. The 2d stage fired on schedule but the 3d stage did not fire.	0	

Vanguard III (SLV-7). United States: Satellite (sphere from which tapered tube extends); scientific payload of 50 lbs. and attached 3d-stage together weight about 100 lbs.	Sept. 18, 1959—estimated 30 to 40 years.	Vanguard satellite launching vehicle 7 stages (3) 1st, liquid (GE); 2d, liquid (Aerojet); 3d, solid (ABL). Gross takeoff weight: Approximately 22,600 lbs. Height: 72 ft. Diameter (base): 45 in.	Dimensions: 20-inch sphere from which a 26-inch tapered tube extends. Experiments: Measurements of earth's magnetic field, solar X-rays, and environmental conditions in space. Shell composition: Highly polished silicon-monoxide-coated magnesium. Antennas: 4 metal rods. Transmitters: (a) 108 mc. at 30 mw., tracking and X-ray and environmental; (b) 108.03 mc. at 80 mw. for magnetometer and command. Power supply: Chemical batteries. Transmitter lifetime: Programed for about 90 days.	Orbit achieved. Provided comprehensive survey of Earth's magnetic fields over area covered; detailed location of lower edge of Van Allen Radiation Belt; accurate count of micrometeors.	319	2,329
Lunik III, Russia translunar earth satellite ("automatic interplanetary station"). Total payload weight in orbit: 614-lbs. scientific satellite. Last-stage rocket, weighing 3,423 lbs. without fuel, also went into orbit. It contained 345 lbs. of scientific equipment.[7]	Oct. 4, 1959, at 5 a.m. Moscow time (Oct. 3, 1959, at 10 p.m. e.d.t., New York time). Down April, 1960.	Not disclosed	Dimensions: Not disclosed. Experiments: Two cameras, developing mechanism and automatic devices for triggering cameras, developing processes and transmission pictures to earth. Also automatic temperature control mechanism. Other experiments not disclosed. Shell composition: not disclosed. Antennas: 4 metal rods. Transmitters: (a) 183.6 mc. at (estimated: between 5 and 20 watts); (b) 39.986 mc. at (not disclosed). Power supply: Solar cells and chemical batteries.	Rocket left Earth at 25,000 m.p.h. The payload separated from the last stage and reached closest point to Moon—4,373 miles—on Oct. 6. When satellite was about 40,000 miles from Moon's surface, the cameras were triggered. They produced photographs of high precision showing 70 percent of Moon's backside. Cameras were operated on Oct. 7, 1959, for 40 mins. Pictures were transmitted to Earth shortly before reaching perigee on Oct. 18, 1959.	Lunik III reached its apogee 292,000 miles from surface of the Earth on Oct. 10; it reached 1st perigee, 24,840 miles from surface of the Earth on Oct. 18, 1959. The 625,000-mile, 15-day, elliptical orbit was highly eccentric.	
Explorer VII, United States: Satellite (2 truncated cones joined at base). Scientific payload and total weight in orbit: 91.5 lbs.	Oct. 13, 1959 (11:31 a.m. e.d.t.). 20–30 years.	Modified Juno II (19A).	Dimensions: 30 in. in diameter, 30 in. long. Experiments: Radiation balance; Lyman-alpha X-ray; heavy primary cosmic ray; micrometeorite; cosmic ray; exposed solar cell; temperature measurements. Shell composition: Fiberglass and sand-blasted aluminum foil. Antennas: 20 mc. turnstile antenna consists of 4 flexible quarter wavelength elements which are unreeled in the plane of the satellite equator from a motor-driven drum on the spin axis: 108 mc. turnstile antenna with 4 rod elements. Transmitters: (a) 108 mc. at 10 mw.; (b) 20 mc. at 600 mw.; (c) 40 mc. at 15 mw.; (d) 60 mc. at 5 mw. Power supply: Solar cells and rechargeable nickel-cadmium batteries.	Satellite went into predicted orbit, all equipment working as programed. Provided significant geophysical information on radiation and magnetic storms; demonstrated method of controlling internal temperatures; first micrometeorite penetration of a sensor in flight; detection of large-scale weather patterns. Tracking beacon ceased transmitting December 1959. Multiplexer on 1 of 4 frequency modulated subcarriers of 2d transmitter providing information on 3 of 7 experiments became so erratic in mid-June 1960 that the data was unintelligible. Period: 101.33 min. Inclination to Equator: 50.3°. Velocity at perigee: 17,285 m.p.h. Velocity at apogee: 16,028 m.p.h.	[8] 342 100	680 520

See footnotes at end of table.

United States and Russian satellites, lunar probes and space probes 1957 to June 1960—Continued

(Official statistics prepared by the National Aeronautics and Space Administration [1])—Continued

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee[2] (miles)	Apogee[2] (miles)
Discoverer VII, United States: Satellite and nose cone reentry capsule. Total weight, approximately 1,700 lbs. (entire 2d stage) including 300-lb. reentry capsule. Launched from Vandenberg AFB.	Nov. 7, 1959. Approximate lifetime, 2 weeks.	Same as Discoverer V.	Same as Discoverer IV	Satellite went into orbit, however, reentry capsule was not released due to malfunction of electrical system and possible lack of stabilization.		
Discoverer VIII, United States (ARPA). Same as Discoverer VII.	Nov. 20, 1959–March 7, 1960.	Same as Discoverer V.	Same as Discoverer IV	Satellite went into orbit, however, although reentry capsule was ejected it was not recovered and search was abandoned.	130	1,035
Pioneer. U.S. lunar probe (paddlewheel; spheroid with 4 solar vanes or paddles). Scientific payload: 372 lbs. Mission: To obtain basic measurements of the lunar environment.	Nov. 26, 1959–0 2:26 a.m.	Atlas-Able stages (3): 1st, U.S. Air Force Atlas ICBM modified to accommodate extra stages; 2d, liquid propellant, adapted from earlier Able rocket vehicles; 3d, solid propellant modified from earlier Able and Vanguard rocket configurations. Gross liftoff weight: 255,000 lbs. plus. Height: 98 ft. Diameter at base: 16 ft.	Dimensions: 39 in. in diameter and 55 in. deep with 4 24- by 24-in. square solar vanes jutting from probe's equator. Experiments: (1) Measurements of 3 specific energy levels of cosmic rays; (2) TV-like scanning device to relay lunar surface picture; (3) solar cells (8,800 in all; 1,200 on each side of 4 solar vanes to create voltage to recharge the probe's chemical batteries in flight (Note: Electronic gear in probe includes 2 transmitters and 2 receivers); (4) micrometorite detector; (5) 2 types of magnetometer; (6) radio wave experiments. Antennas: 4 dipole aluminum rods. Transmitters: 2 ultrahigh frequency 378 mc. transmitters at 5 watts. Power supply: Nickel cadmium batteries rechargeable by solar cells (see above). The payload also contained a small engine to provide inflight velocity corrections. The probe payload had 2 thrust chambers, 1 to step up velocity, the other to supply reverse thrust when probe approached moon's gravitational field. Each chamber could deliver 20 lbs. of thrust.	Countdown was normal and liftoff went as scheduled. 46 sec. after liftoff, 2d stage guidance transponder no longer responded to interrogation. At 104 sec., 2d stage telemetry was lost. Atlas booster and sustainer operated as scheduled but about 45 sec. after launch the plastic shroud covering the lunar probe fell off. As the shroud fell away, the vehicle was approaching maximum atmospheric pressure loads. With the shroud gone, the payload was torn off. Radar indicated that the 2d stage ignited but there was no indication that it separated. Reason for the shroud dropoff and mission failure is under study.	(Altitude unknown.)	

Discoverer IX. United States. Satellite and nose cone reentry capsule. Total orbital weight is 1,700 lbs. including fuel, less 2d stage casing and 300-lb. capsule. Launched from Vandenberg Air Force Base, Calif. Entire 2d stage is designed to go into orbit.	10:51 a.m. P.s.t. Feb. 4, 1960–0.	Modified Thor IRBM—1st stage. Agena—2d stage. Gross liftoff weight: Approximately 108,500 lbs. Height: 78 ft. Diameter at base: 8 ft.	Dimensions: Height 19.2 ft.; diameter 5 ft. Experiments: Launching technique, propulsion, communications, orbital performance, recovery techniques, and advanced engineering tests. Payload: Instrumentation, telemetry, and reentry capsule is 27 in. long and 33 in. in diameter. It contains advanced engineering test and recovery equipment. The satellite guidance equipment includes an inerital reference package, an infrared scanning device, a pneumatic jet control system, and a hydraulic control system. The capsule is designed to be ejected from the satellite by a timing device which triggers the vehicle into position and separates it by a series of explosive bolts and springs. The capsule's retrorocket would slow it to reentry velocity. At an appropriate altitude, a parachute would be automatically deployed to slow the vehicle. To aid in recovery, the capsule contained a radio to transmit signals, aluminum chaff to be released upon opening of the parachute, and a rotating high frequency stroboscopic light.	Vehicle rose from pad as programed. Telemetry was lost soon afterward. Radar showed that the Discoverer failed to achieve orbital velocity and fell back to Earth. The failure is attributed to a malfunction in the tower which moves the fueling equipment from the space vehicle. This malfunction damaged the 2d stage and caused a premature shutdown of the 1st stage.	0	0
Discoverer X. Same as Discoverer IX.	12:14 p.m. P.s.t., Feb. 19, 1960–0.	Same as Discoverer IX.	Same as Discoverer IX	Vehicle rose from pad as programed but veered off course at 20,000 ft. and headed for nearby seacoast cities. Range safety officer destroyed vehicle 52 sec. after launch.	0	0
Midas (Missile Defense Alarm System) I. U.S. Air Force. Launched from Cape Canaveral, Fla. Entire 2d stage is designed to go into orbit. Orbital weight after fuel exhaustion is approximately 4,500 lbs., including the 1,700-lb. Agena casing.	12:25 p.m. E.s.t., Feb. 26, 1960–0.	Modified Atlas—1st stage. Agena—2d stage. Gross liftoff weight: 260,000 lbs. Height: 99 ft. Diameter at base: 16 ft.	Payload: Infrared, telemetry, communications, and other advanced engineering test equipment. Dimensions: Satellite is cylindrical in shape, 22 ft. long, and 5 ft. in diameter. Experiments: To establish workability of the Atlas-Agena combination, launch procedure, and tracking and communications systems. The Midas program is designed to detect heat radiating from the exhaust of ballistic missiles and to feed detections into the air defense warning net. It will increase the warning time against hostile ballistic missiles to 30 mins.	Atlas performed as programed. About 5 minutes after launch, just about the time when the Atlas should have separated and fallen away from the Agena, telemetry was lost. It is presumed that 2d stage separation did not occur and the vehicle burned up upon reentering the atmosphere about 2,500 miles downrange from Cape Canaveral.	0	0

See footnotes at end of table.

United States and Russian satellites, lunar probes and space probes 1957 to June 1960—Continued

(Official statistics prepared by the National Aeronautics and Space Administration [1])—Continued

Name, by, type orbit, and payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perihelion (miles)	Aphelion (miles)
Pioneer V. (1960 Alpha) U.S. space probe (paddle-wheel sphere with 4 solar vanes): From AMR, Cape Canaveral, Fla. Total payload weight: 94.8 lbs., of which experimental instruments comprise slightly over 40 lbs.; structure, electronics, and power, the remainder. Mission: To provide information about space between the orbits of Venus and Earth; to test the feasibility of long-range interplanetary-type communications; and to improve methods for measuring astronomical distances.	8 a.m. e.s.t., Mar. 11, 1960. Lifetime of 100,000 yrs. expected.	Thor-Able stages: 1st, improved Thor IRBM modified for extra stages; 2d, liquid propellant rocket modified from earlier Vanguard and Thor-Able vehicles (6 small spin rockets ring its surface); 3d, solid-propellant rocket adapted from Vanguard and Able I vehicles. Gross liftoff weight: Over 105,000 lbs. Height: 90 ft. Diameter at base: 8 ft.	Shape and dimensions: 26-in. diameter sphere with 4 solar vanes jutting from its equator. Solar vanes are each 18 by 14 in. Shell—Composition: Fiberglass and aluminum. Experiments: Measurements of radiation, magnetic fields, micrometeoroid activity, and temperatures. Transmitters: 2 UHF 378-mc.—a 5-watt which on command becomes an amplifier for the 2d which is a 150-watt [11] transmitter. Antenna: Single-stub antenna. Power supply: Nickel cadmium batteries rechargeable by the cells on the 4 solar vanes. Each vane carries 1,200 solar cells.	Period: 312 days (estimated). Speed (estimated): Perihelion, 78,000 m.p.h.; Aphelion, 63,300 m.p.h. Orbital path: 514,500,000 miles (estimated). Many "firsts" in long range communications,[11] gauged solar flare effects, particle energies and distribution, and magnetic field phenomena in interplanetary space.	[9] 74, 967, 000	[10] 92, 358, 000

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee[2] (miles)	Apogee[2] (miles)
Explorer. U.S. satellite: Fired from AMR, Cape Canaveral, Fla. Mission: To analyze the energies of electron and proton radiation in the Van Allen Radiation Zones over an extended period of time. Total payload weight: 22.8 lbs., of which the instrument pack assembly, is 12.19 lbs.; the instrument housing assembly, 2.47 lbs.; the solar cell box, 7.07 lbs.; and other assembly items, 0.87 lbs. 4th stage casing was to the remain attached to the payload. Casing weight was 12.5 lbs. Bring total weight in orbit to 35.3 lbs.	8:35 a.m. e.s.t. Mar. 23, 1960–0.	Juno II stages: 1st, modified Jupiter IRBM; 2d, grouping of 11 scaled-down solid-fuel sergeants; 3d, 3 scaled-down sergeants; 4th, single scaled-down sergeant. Gross liftoff weight: 120,000 lbs. Height: 76 ft. Diameter at base: 8¾ ft.	Dimensions: Cylinder. 21 in. long and 7 in. in diameter. A 12- by 12- by 9-in. box on which the solar cells were mounted was constructed about the cylinder. Experiments: Detailed measurements of energetic particles in the Van Allen Radiation Zones and of temperatures inside and outside the payload. Shell composition: Aluminum. Antenna: Single dipole using payload structure and 4th stage casing. Transmitter: 300-milliwatt operating at 108.03 mc., capable of transmitting data continuously on 5 channels. Power supply: Nickel cadmium batteries recharged by 1,184 solar cells mounted on the box-like structure surrounding the cylindrical instrument package.	Ground stations lost communications with the vehicle after 2d-stage burnout. Launch inclination: 28° from equator.	0	0
Tiros (Television and Infra-Red Observation Satellite) I.[12] (1960 Beta) U.S. meteorological satellite: Launched from AMR, Cape Canaveral, Fla. The satellite is covered on its top and sides by over 9,200 solar cells. 3 pairs of spin rockets and the transmitting antenna are located around baseplate. On top in the center is a receiving antenna. Total payload weight: 270 lbs.	6:40 a.m. e.s.t. Apr. 1, 1960 (years, 50–100; useful lifetime, 3 months).	Thor-Able (see Pioneer V).	Dimensions: 42 in. in diameter; 19 in. high, cylindrical in shape. Experiments: 2 TV systems—1 wide angle, 1 narrow angle, photograph cloud cover and transmit images to Earth. Other instruments: Telemetry, command, and an attitude sensor system. Shell composition: Aluminum and stainless steel. Antennas: Turnstile transmitting; 1 receiving. Transmitters: For tracking purposes and providing information on attitude, equipment operation, and environment, 2 30-mw. beacon transmitters operating on 108 mc. and 108.03 mc. Connected to each TV system is a 2-watt FM transmitter operating at 235 mc. for relaying picture information. Power supply: Nickel cadmium batteries charged by solar cells. Transmitter lifetime: 300 hrs.	Period: 99.19 mins. Speed: approximately 18,000 m.p.h. Orbital path: Approximately 27,000 miles. Launch inclination) 48.327° to the Equator. Because of an apparently inoperative relay, interrogation was ceased June 28, 1960, after reception of 22,952 highly successful cloud cover photographs.	428.7	465.9

See footnotes at end of list.

United States and Russian satellites, lunar probes and space probes 1957 to June 1960—Continued

(Official statistics prepared by the National Aeronautics and Space Administration [1])—Continued

Name, by, type, orbit weight, payload weight	Lifetime	Launching vehicle	Payload instrumentation	Test results	Perigee[2] (miles)	Apogee[2] (miles)
Transit I–B. (1960 Gamma) U.S. Navy satellite (sphere): Launched from Cape Canaveral, Fla. Total weight in orbit: 265 lbs.	7:03 a.m. e.s.t., Apr. 13, 1960 (estimated at 16 mos.).	Thor-Able-Star: 1st stage, modified Thor IRBM (liquid fuel); 2d stage, Able-Star orbital vehicle. Able-Star has capability for stopping and restarting in flight. It also has a system for attitude control during non-power (coasting) flight (liquid fuel). Diameter at base: 8 ft. Height: Over 79.3 ft. Launch weight: Over 105,000 lbs.	Dimensions: 36-in. diameter. Banks of solar cells ring sphere along equator. Shell composition: Fiberglass. Antenna: Silver-painted spiral band on satellite surface. Power supply: Chemical batteries and solar cells. Transmitters: 4—(*a*) 54 mc., (*b*) 162 mc., (*c*) 216 mc., (*d*) 324 mc. Transmitter lifetime: 3 mos. Other satellite instruments: (*a*) 2 ultra-stable oscillators (radio frequency generators) in temperature-resistant Dewar flasks. Each oscillator can transmit on 2 frequencies. (*b*) Infrared scanner to measure satellite's rotation. (*c*) 2 receivers. (*d*) 2 telemetering gathering and sending devices. Experiment: To determine the feasibility of and improve equipment for providing a global all-weather navigation system that is more reliable than systems now in use under any weather conditions. Such a system would enable ships and aircraft to locate precisely their positions on earth regardless of weather.	Period: 96 mins. Speed: About 18,000 m.p.h. Inclination to Equator: 51°.	233.0	479.0
Discoverer XI. (1960 Delta) United States satellite and nose cone reentry capsule. Launched from Vandenberg Air Force Base, Calif. Total weight in orbit: 1,700 lbs., including 2d stage casing and 300-lb. capsule.	3:30 p.m. e.s.t., Apr. 15, 1960, to Apr. 26, 1960.	Thor-Agena. (See Discoverer IX.)	Same as Discoverer IX except that about 10 lbs. of instruments were installed in the 2d stage casing (satellite) for a tracking experiment connected with the Transit development program. The Transit instrument package consists of a Doppler beacon and external lights for optical tracking by Baker-Nunn cameras of the Smithsonian Astrophysical Observatory. (See Transit 1–B.) Discoverer program objectives are to gather data on satellites and their behavior, on stabilization of a satellite in orbit, and on techniques of recovering objects that have gone into orbit.	Launch inclination: 80.1° to Equator. Period: 92.25 mins. Orbital speed: About 18,000 m.p.h. Other data: 2d stage casing with capsule went into Polar orbit. Capsule was ejected. The capsule was not observed as descending into the recovery area, and recovery was not attempted.	100.0	380.0
		Delta: 1st stage,	Mylar polyester sphere covered with vapor-	Did not achieve orbit due to ap-	0	0

Echo. Launched from Cape Canaveral, Fla. Total orbit weight 240 lbs. including detached 3d stage casing. 190 lb. payload.	5:16 a.m. e.d.t., May 13, 1960–0.	Delta: 1st stage, modified A.F. Thor IRBM; 2d stage, liquid rocket modified from Vanguard with radio guidance; 3d stage, solid rocket modified from Vanguard with motor mounted on spin table. Liftoff weight: 112,000 lbs. 92 ft. high. 8 ft. diameter at base.	Mylar polyester sphere covered with vapor-deposited aluminum; 100 ft. in diameter; in magnesium packaging. Telemetry beacon in 3d stage; casing designed to follow sphere into orbit. Operating at 108.06 mc, continuous for 6 to 10 days (est.) at 60 mw; powered by Mercury batteries; designed as passive communications satellite with aluminum coating to provide radio wave reflectivity of 98 percent up to frequencies of 20,000 mc.	Did not achieve orbit due to apparent malfunction in the attitude controls on 2d stage and failure of 3d stage to receive ignition signal. Payload separation, ejection and inflation was to have been initiated by 3d stage ignition signal.	0	0
Sputnik IV (1960 Epsilon) "Spacecraft," U.S.S.R. Launching site undisclosed. Total weight in orbit 10,008 lbs., including 5,512 pressure cabin, 3,250 lbs. instruments.	6 p.m. e.d.t., May 14, 1960. Estimate relatively brief lifetime.	Multi-staged; details not disclosed.	A 2-part craft with undisclosed shape and dimensions. "Dummy spaceman" with environmental control system. 19.995 mc transmitter for both telemetry and "telephone" systems. Tape of voice transmitted to ground stations. Chemical and solar batteries for power supply.	Launch and near circular orbit achieved. After retrorocket firing on May 19, 1960, pressure vessel apparently separated from cabin but due to orientation fault went into lopsided orbit instead of reentering the atmosphere.	[13] 88.5 [14] 191	[13] 228.7 [14] 429
Midas II (1960 Zeta). U.S. Air Force. Launched from Cape Canaveral, Fla. Total weight in orbit approximately 5,000 lbs., including entire 2d stage.	12:37 p.m. e.s.t., May 24, 1960. Estimated 40 months.	Atlas-Agena: 1st stage modified Atlas ICBM; 2d stage, Agena "A". Liftoff weight, approx. 260,000 lbs.; 99 feet high; 10 feet base diameter.	Cylindrical. 22 ft. high; 5 ft. in diameter. Instrumentation details not released. Includes infrared telemetry and communications equipment. Information on battery-powered transmitters not available.	Launch inclination 33° to Equator. Period 94.3 minutes. Velocity 17,045 miles per hour (injection velocity). Orbit achieved. 2 days after launch, data link telemetry transmitting infrared scanner information to ground stations ceased functioning.	292.1	322
Transit II–A, (1960 Eta). U.S. Navy, weight 223 lbs. plus 42-lb. pickaback satellite.	June 22, 1960, 1:54 a.m. edt. Both satellites est. 50 years; transmitting lifetime up to 1 year.	Thor-Able-Star: Stages (1) Modified USAF Thor IRBM; (2) USAF Able-Star. 79.3 ft. high; 8 ft. base diameter. Lift-off weight: Over 105,000 lbs.	(a) Two ultra-stable oscillators; infrared scanner to measure satellite's rotation; electronic clock as time standard; Canadian receiver to measure galactic noise. (b) 42-lb. pickaback satellite with instruments to measure solar radiation and other information on ionosphere. Completely solar powered. Nickel-cadmium battery for power storage. Operating on (a) 54, 324, 162, 216 and (b) 108 mc.	Two satellites placed in Earth orbit. Both transmitting clearly. Period: 101.5 minutes. Inclination to Equator: 65°.	460	563
Discoverer XII. Same as Discoverer XI.	3:01 p.m. P.s.t., June 29, 1960–0.	Same as Discoverer XI.	Same as Discoverer XI, except extra instrumentation was added in an effort to determine the causes of previous Discoverer failures.	Failed to achieve orbit, reentered the atmosphere and burned up over the South Pacific.	0	0

See footnotes at end of table.

[1] Except where indicated, this chart does not include description and weights of spent rocket casings, etc., that have gone into orbit or flight trajections along with payloads.

[2] All distances are given in statute miles above the surface of the earth.

[3] Altitude: 40,000 to 70,000 ft.

[4] Altitude: About 70,700 statute miles.

[5] Altitude: 963 miles.

[6] Altitude: 63,580 miles.

[7] These are unofficial figures culled from U.S. press, Pravda, Moscow radio, etc.

[8] Oct. 27, 1959.

[9] Aug. 10, 1960 (estimated).

[10] Jan. 13, 1961 (estimated).

[11] The 150-watt transmitter has an output 20 times greater than any transmitter used in prior space experiments. It was designed to permit contact with Earth from a 50-million-mile distance. The 150-watt transmitter was successfully turned on on May 8, 1960, when Pioneer V was 8,001,000 miles from the Earth. Apparent weakness of the batteries caused a cessation of operation of the 150-watt transmitter on May 21, 1960. Final acquisition of data was received from the 5-watt transmitter on June 26, 1960, from a record distance of 22.5 million miles. A total of 138.9 hours of data was received.

[12] This is the 1st of 2 Tiros satellites scheduled for 1960. It is not equipped with infrared radiation sensors to map relative temperatures of the Earth's surface. Both satellites are experiments to determine whether meteorological satellites are feasible and to refine instruments and techniques for an operational meteorological satellite system.

[13] Original apogee and perigee.

[14] Apogee and perigee after firing of retrorockets May 19, 1960.

NOTE.—All statistics listed above, with exception of the Russian figures, are official. Statistics from here on are subject to updating when study of data has been completed. All Discoverer satellites are sponsored by the Advanced Research Projects Agency of the Department of Defense and are launched by the Air Force. All statistics on Discoverer experiments have been supplied by ARPA.

INDEX

A

Page

Ablation 861, 914, 916, 950–951
Able (*see also* Atlas-Able; Thor-Able.)
Able 642
Acceleration. (*See* G-forces.)
Accelerators. (*See* Particle accelerators; Plasma accelerators; Centrifuges.)
Advanced Falcon, air-to-air missile 935
Aerial jeep 872, 874
Aerobee-150, sounding rocket 639
Aerocycle. (*See* Aerial jeep.)
Agena (*see also* Thor-Agena.)
Agena 621, 641
Agena B. (*See also* Atlas-Agena B.)
Agena B 667
Ailerons. (*See* Control surfaces.)
AFBMD. (*See* Air Force Ballistic Missile Division.)
Air Crew Equipment Laboratory 733
Air Force:
  Agreement with NACA on X–15 928
  Cooperation with NASA on testing Nova engine 979–981
Air Force Ballistic Missile Division 664
Air Force Missile Test Center 770, 930, 979–982
Air Research and Development Command. (*See* Particular research centers, e.g., Air Force Missile Test Center, Wright Air Development Center, etc.)
Airplanes (*see also* Specific types of airplanes, e.g., F–102, X–15.)
  Bombers 909
    B–58 (Convair) 909
    B–70 (North American) 909
  Convertiplane, Bell XV–3 tilting rotor 872
  Fighter:
    F–102 ..... 926, 928
    F–104–A 926, 928
  Hypersonic: X–15 ..... 926, 928
  Multiengine, effects of noise 878, 881–882
  Nuclear 847, 981–986
    Comparison with conventional aircraft 986
    Range 981
  STOL 867–869, 876
  Transport 869, 871, 892–893, 903, 928
    Supersonic 892
      Comparison with subsonic 892–893
      Design 892
      Drag 892–893
      Flight paths 895
      Flight performance 888, 891–892, 900
      Noise 882, 884–886
      Stability and control 892, 894–895
      Takeoff and landing 885–887
  VTOL 867–876
    Aerial jeep 872, 874
    Ducted fan 867, 872, 874
    Propeller driven 867, 869–870
    Rocket 867
    Rotor 867, 872–873
    Transport 869, 871
    Turbojet 867, 872–875
    Turboprop 869, 871–872, 875
  VTOL–STOL 869

Page

Airports (*see also* Heliport) ... 869
Noise ... 878, 882, 885, 887
Altimeters, radio ... 629
Ames Research Center ... 876, 924
Ammonia ... 584
Amplifiers ... 683
Antennas ... 654, 655, 677, 757, 763, 770, 851, 859
Directional ... 683
Goldstone ... 683, 685 764, 766,
Parabolic ... 757
Quadrihelix ... 757
Tracking ... 656
Antiballistic missiles. (*See* Missiles, antimissile.)
Antigua ... 756
Antimissile missiles. (*See* Missiles, antimissile.)
Antisatellite missiles. (*See* Missiles, antisatellite.)
Antraquinone ... 861
Argon ... 577
Army ... 578, 664
Army Ballistic Missile Agency ... 791
Army Map Service ... 770
Army Signal Research and Development Laboratories ... 664
Astronauts (Project Mercury):
Biographies ... 740–744
List ... 731
Selection and training ... 730–744
Special assignments ... 731
Astronomy (*see also* Asteroids; Comets; Meteoroids; Moon; Planets; Stars; Sun) ... 610–616, 632
Asteroids ... 613
Atlantic Missile Range ... 654, 700, 714, 721, 727, 729, 749, 754, 756, 757, 768, 938
Atlas (*see also* Thor-Atlas) ... 641–642, 647, 778, 786, 948, 977
Atlas-Able ... 617, 786
Atlas-Agena B ... 618–619, 786–788
Atmospheres (*see also* Clouds; Ionosphere; Meteorology; Storms):
Earth ... 575–577, 581, 632, 633
Jupiter ... 580, 583–584
Mars ... 580, 582, 637–638, 841, 844
Moon ... 575, 580
Planetary ... 575, 580–584, 613, 835–846, 973
Saturn ... 580, 583–584
Sun ... 575
Venus ... 580–581, 841, 844
Atmospheric models ... 645
Atomic Energy Commission, cooperation with NASA on nuclear rocket ... 827, 830–831
Atomic Energy Research Establishment (Great Britain) ... 608
Attitude control. (*See* Control, attitude.)
Aurora ... 586, 588, 594–596, 635
Australia ... 757, 764, 770
Auxiliary power sources:
Chemical ... 664, 814
Nuclear ... 819–822
Solar ... 664, 816–817, 857, 859

B

B–58 (Convair) ... 961
B–70 (North American) ... 909
Baker-Nunn. (*See* Cameras, Baker-Nunn; Tracking, photographic; Tracking stations, Baker-Nunn.)
Ballistic flight, manned ... 724, 727
Ballistic missiles. (*See* Missiles, ballistic.)
Balloons ... 575, 643, 651

Page
Batteries (*see also* Auxiliary power sources):
Chemical 664, 814
Storage 816
Beacon 992
Bearings, materials 849
Beatty, Nev 930
Bell Telephone Laboratories, Holmdel, N.J 671
Benzoic acid 861
Bermuda 727, 729
Beryllium 847, 950
Big Joe 714, 716, 720, 887, 888
Bioscience Advisory Committee. (*See* National Aeronautics and Space Administration.)
Biomedicine. (*See* Space medicine.)
Biosciences 971, 975
Biotechnology (*see also* Human engineering) 972
Blossom Point, Md 770
Bodies:
Blunt 945, 947, 949, 950, 952
Conical 945, 947, 948
Shape factors 945, 947, 949, 950
Stability 945
Boeing 707 961
Bomarc, ground-to-air missile 903, 935
Bonneville Salt Flats 930
Boosters. (*See* Launching vehicles.)
Borides 850, 851
Boundary layers 947
Laminar 885
Noise 882–885
Turbulent 885
Bullpup air-to-ground missile 935

C

California 730
Cameras (*see also* Television; Photography) 654, 656, 681
Baker-Nunn 756, 758–759
Canada, ionosphere research 594
Canary Islands 727, 729
Cape Canaveral. (*See* Atlantic Missile Range.)
Capsules 700–701, 714, 716, 720, 722, 724, 726–727, 729–730, 768, 861–863, 887–888, 912–913, 916
Carbides 850, 851
Carbon dioxide 577, 580
Carpenter, Malcolm Scott, biography 740
Castor (rocket engine) 714
Centaur 618–619, 621, 624, 642, 786, 789, 790, 791, 821
Centrifuges 922–923, 930
Ceramics 850–851, 853, 905
Cesium 805
Charged particles. (*See* Particles, energetic.)
Clouds 647–651, 654–663
Coatings, protective. (*See* Protective coatings.)
Cobalt alloys 849, 851
Columbium. (*See* Niobium.)
Comets 615
Communications (*see also* Space communications) 586, 594, 646, 668–685, 752, 770, 772–773, 775
Future commercial, military, and scientific requirements 668
Reliability 668
Global 668
Computers 747, 752, 754, 773, 926
Computing center 768, 770, 773
Contributors, alphabetical list of VI
Control (*see also* Guidance):
Attitude 621, 624, 629–632, 697, 700, 701, 703, 924
Human versus automatic 920
Human problems 920–924

Page

Control centers 747, 752, 768, 770, 773, 775
Control sticks 924, 926
  Side-located 924
Control surfaces 897, 900, 930, 936, 967
Controls 667, 924,–925, 964
  Aerodynamic 897, 900, 930, 936, 967
  Reaction 656, 697–699, 720, 909, 924, 929,–930, 941, 967
Cooling systems 831, 905, 908, 950,–951
Cooper, Leroy Gordon, biography 740, 742
Copper 947, 950
Corrosion 819, 848, 983
Corvus, air-to-ground missile 935
Cosmic dust clouds 615
Cosmic radiations (*see also* Particles, energetic) 596, 611

D

DC–8 (Douglas) 961
DOD. (*See* Department of Defense.)
DX priority 745
Data processing 646, 752, 754
Data transmission 656, 668, 757, 770, 773–774
Deceleration. (*See* G-forces.)
Delta (*see also* Thor-Delta) 640, 642, 779, 782, 783, 786
Department of Defense (*see also* Air Force, Army, etc.) 646, 657
Department of the Air Force. (*See* Air Force.)
Department of the Army. (*See* Army.)
Department of the Navy. (*See* Navy.)
Discoverer 779, 784, 785, 994, 995, 996, 997, 998, 1000, 1001, 1004, 1005
Drag 892, 909–910, 938, 943, 951
Dynamics, structural 951–965
  Definition 951, 953
Dynasoar 863, 909–910, 914, 922, 926, 954, 956–957, 964–965

E

Earth (*see also* Atmosphere; Ionosphere; etc.) 610, 612, 613, 615, 634–635, 641, 837, 841, 844
  Internal structure 685, 691
  Shape 605, 685, 687–691
  Size 685, 687–691
East Grandforks, Minn 764
Echo, passive communications satellite 669–674, 1005
  Comparison with active type 674
  Ground stations 669–671
  Multiple sphere launch 671–672
Edwards Air Force Base. (*See* Air Force Missile Test Center.)
Electrons 586, 807–808, 812
Elastomers 848
Electron gun 807
Ely, Nev 930
Energy transforming materials 849
Engines:
  High speed 878–879, 900–908
    Altitude and flight speed capabilities 900–903, 905–907
    Fuels 905–906
    Ramjet 903–906
    Temperature problems 905–908
    Turbojet 847, 905
    Turboprop 903
  Ion. (*See* Rockets, ion; Propulsion, ion.)
  Nuclear (*see also* Power sources, nuclear; Reactors, nuclear; Rockets, nuclear) 981–986
    Closed heat exchange system 981, 983, 985
    Direct air cycle system 981, 983, 984
  Rocket (*see also* Rockets) 930, 932, 968
    1½-million-pound thrust booster 791, 977–982
    Materials 848

Page
Entry 835–846
Environment, extraterrestrial (*see also* Space environment) 971–973, 975
Materials 847–848
Escape system, Mercury project 703, 710–711
Explorer VI 621, 997
Explorer VII 640, 651–653, 999

F

F–102 926
F–104A 924, 926–928
FPS–16, tracking radar 770
Facilities, test:
Hypersonic 961, 967
Engine 979, 982
Radiant heating 916
Structure vibration 953
Fairbanks, Alaska 764
Falcon (*see also* Advanced Falcon).
Falcon air-to-air missile 935
Fans, ducted 872, 874
Fatigue, structural 888
Fields (*see also* Gravitation, Magnetic fields).
Fields 599–610, 685
Figures, list of VII
Flaps 867
Flight controls. (*See* Controls; Control sticks; Control surfaces.)
Flight medicine. (*See* Space medicine.)
Flight paths (*see also* Trajectories, Orbits) 878, 885, 887, 926, 928, 930, 965, 967
Hypersonic gliders 910–912
Supersonic transport airplanes 895, 897
Flight research 928–934
Flight Research Center 922, 930
Flight simulators 733–739, 745, 920–928, 930
Stationary 921–922, 926
Centrifuge 922–923, 930
Flight test ranges 929–931
Flow:
Hypersonic 957, 961
Blunt bodies 947
Slender bodies 947
Supersonic 892, 938, 940
Turbulent 878
Flutter (*see also* Vibration) 953–955, 957–962
Panel 957–964
Wing 957
Control 957
Flying platform 872–873
Hiller 872, 874
"Flying test beds" 869, 872
Fort Monmouth, N.J 654, 657
Fort Stewart, Ga 770
Fuel sloshing 957
Fuel tanks 831, 861, 765
Fuels 667, 786, 824, 827–828, 905, 906, 977, 981

G

G-forces 723, 724, 727, 731, 735, 835, 836, 837, 922, 924, 930, 943–944, 973–974
Galaxy 610, 613
Gamma-rays 611
Gases:
Dissociation 577
Interplanetary 613
Interstellar 613
Ionized 602

Page

General Electric Co. 647
Generators. (*See* Auxiliary power sources.)
Geodetics 605–608, 685–696
Geophysics 685–696
Geoid (*see also* Earth, shape) 687
Glass 950
Glenn, John Herschell, biography 742
Glennan, T. Keith, letter to Hon. John Stennis III
Gliders, hypersonic 909–910
  Aerodynamics 909–910
  Descent 910–911
  Heating, aerodynamic 910
  Human factors 922–924
  Landing 926–928
  Range 909–910
  Speed 909
  Stability and control 909–910
Goddard Space Flight Center 646, 747, 768
Goldstone, Calif 671, 683, 685, 764, 766
Grand Bahama 754
Grand Turk 756
Graphite 919
Gravitation 605–610, 632, 685, 687–689, 973–974
  Jupiter 580, 584
  Mars 580
  Moon 580
  Saturn 584
  Venus 580
Grissom, Virgil Ivan, biography 742, 743
Ground handling, spacecraft 752
Ground support equipment 752, 753
Guidance 621, 835, 841, 844, 922, 932, 935, 943, 968
  Attitude control 624, 629, 631–632
  Celestial 626–628
  Optical 626
  Radar 626
  Radio 621, 626, 628
  Spacecraft 624, 752–754, 756
Guidance, midcourse 621, 624, 625–628
  Celestial 626–628
  Engines 621,626
  Radio 621, 628
Guidance systems:
  Delta 779
  Inertial 786
  Scout 779
  Titan 779
Guidance, terminal 624
  Doppler radio techniques 629–630
  Horizon scanners 629–630
  Radio altimeters 629–630
Gusts. (*See* Loads, gust.)

H

Habitation, outer space. (*See* Life, extraterrestrial.)
Hafnium Carbide 851
Hawaii 757
Hawk (Army) ground-to-air missile 935
Heat exchangers 983
Heat sinks 947
Heat transfer (*see also* Ablation) 865, 867, 947, 950–951, 983
  Engines, jet 905
  Fuels 905, 907
  Radiation 857, 912–914, 916

Page
Heating:
Aerodynamic 835, 837, 841, 843–846, 910–914, 935, 943, 945, 947–950
Base 938
Helicopter rotors: Vibration 953
Helicopters 867
Heliport (*see also* Airports) 869
Helium 584, 983
High speed particles. (*See* Meteorids.)
Hiller flying platform 872, 874
Homing devices 968
Horizon scanners 629–630, 667, 720, 967
Hound Dog (Air Force) air-to-ground missile 935
Hoyle, Fred, theory of universe 610
Heat shields 714, 720
Human engineering and physiology 920–924
G-factors 922, 924
Sound 877–878, 882, 888
Hydrogen 584, 578, 786, 831
Hydrogen, liquid 824, 826–827, 831, 865, 908, 964
Comparison with conventional jet fuels 908
Pump 831

I

IBM 704 computer 773
ICBM. (*See* Missiles, ballistic.)
IGY. (*See* International Geophysical Year.)
IRBM. (*See* Missiles, ballistic.)
Inconel X 929–930
Information theory 685
Infrared detectors 649, 651, 656, 664
Intercontinental distances, measurement 691
Intercontinental ballistic missile. (*See* Missiles, ballistic.)
Intermediate range ballistic missile. (*See* Missiles, ballistic.)
International Geophysical Year 575, 586, 632, 640
Interplanetary flight 617–624, 749, 751, 797, 824, 827, 835–846, 865
Interstellar cloud 615
Interstellar dust 615
Interstellar gas 613
Ion propulsion. (*See* Propulsion, ion; Rockets, ion.)
Ion sheet 967
Ion sources 807
Ions (*see also* Ionosphere; Propulsion, ion) 584, 805, 807–808, 812
Ionization 584, 586, 805–807, 808, 812, 814, 967
Ionosphere 584–594, 639
Arctic regions 586
D-layer 584, 586
E-layer 584, 586, 591
F–1–layer 584, 586, 591
F–2–layer 584, 586, 591
Electron density 588
Jupiter 586
Moon 588
Research instrumentation 591, 594
Research program 588–592
Venus 586
Windows 591
Iron 855, 856

J

JMSAC. (*See* Joint Meteorological Satellite Advisory Committee.) 646
JPL (CIT). (*See* Jet Propulsion Laboratory, California Institute of Technology.)
Jet Propulsion Laboratory, California Institute of Technology 621
Jets, deflection 872, 876

53795 O - 60 - 29

Page
Jodrell Bank ... 685
Johannesburg, South Africa ... 764
Johnsville Navy Development Center ... 734
Joint Meteorological Satellite Advisory Committee (JMSAC) ... 646
Juno II ... 640, 641, 777, 779
Jupiter ballistic missile ... 580, 583–584, 586, 779, 797, 935, 948, 950

K

Kaena Point, Hawaii ... 654, 657
"Kety Report." (*See* NASA Bioscience Advisory Committee Report.)
Kinescopes ... 656
Kinetic energy ... 835
KIWI–A (nuclear reactor) ... 831–832

L

Landing (*see also* Entry) ... 926–928, 930, 953, 965
  Gears ... 929, 965
  Lunar ... 617, 618, 629, 786, 791
  Planetary ... 835–846
  Simulation ... 926
Langley Research Center ... 669, 816, 876, 922, 924, 926
Launching ... 714–715, 718–719, 922, 951, 954
  Base heating problem ... 938
  Spacecraft ... 749, 754
  Wind problem ... 936, 939
Launching facilities ... 747–754, 756, 764
Launching vehicles (*see also* individual types, e.g., Saturn, Centaur, Nova, etc.) ... 617, 647, 656, 704, 714, 745–746, 749, 777–791, 831, 861, 908, 922, 938, 964, 968
  Antimissile ... 967
  Clustered ... 977
  Nova ... 977–981
  1½-million-pound thrust booster ... 977–981
Letter of submittal from Dr. Glennan to Senator Stennis ... III
Lewis Research Center ... 803, 805, 808, 837, 851
Life, extraterrestrial ... 611, 971–973, 975
Life, origin of ... 973, 975
Lincoln Laboratory, Massachusetts Institute of Technology ... 968
  Millstone ... 671
Lithium ... 848
Little Joe ... 704, 714, 724, 745–746
Loads:
  Acoustic ... 878, 881–882, 885
  Aerodynamic ... 943
  Blast ... 953
  Gust ... 953, 954, 956, 964
  Landing ... 953
  Wind. (*See* Wind effect.)
Los Alamos Scientific Laboratory ... 827
Lovelace Clinic ... 731
Lubricants ... 849
Lunar flight ... 617–624, 749, 751, 786, 800–802, 835, 865, 977
Lunar impacts, lunar landings. (*See* Landings, lunar.)
Lunar orbiters ... 617, 618
Lunik I, II, III ... 620, 993, 998, 999

Mc

McDonnell Aircraft Corp ... 720, 724, 725, 737, 745

M

Magnetic fields ... 578, 588, 596, 599–606, 619, 621, 632, 638, 639, 812, 814
Magnetic storms ... 602
Magnetohydrodynamics ... 591, 805–814
Manned orbiting laboratories (*see also* Spacecraft, manned) ... 745, 973
Mars ... 580, 582, 613, 616–620, 624, 637, 638, 681, 683, 791, 797, 800, 803, 804, 821, 824, 827, 841, 842.

Page
Masers 683
Matador (Air Force) ground-to-ground missile (winged) 935
Materials:
Ceramic 905, 919
Corrosion 819, 848, 983
Cyrogenic 848
Ductile 849, 850
Effects of radiation 986
High temperature 847, 849, 851, 852, 905, 914, 916, 918–920, 947
Plastics 853, 859, 861, 916, 950
Refractory metals 847, 849–852
Research 747, 855
Solid state physics 853–856
Spacecraft 859, 916–920
Strength 851–853, 855, 856
Strength to weight ratio 848
Temperature ranges 848
Medicine. (*See* space medicine.)
Mercury project 605, 697, 745, 768, 786, 819, 924, 964, 972
Astronauts:
Operational experience 740
Selection and training 730–744
Special assignments 731
Atlas booster 700, 702–704
Attitude control 697, 700, 701, 703
Ballistic capsule 697, 699–705
"Boilerplate capsules" 704, 745
Biographies of astronauts 740–744
Biomedical requirements 731
Booster 703, 745
Capsule:
Construction 720, 723
Engineering mockup 720, 722
Flight tests 724, 726, 727
Instrumentation 697, 698, 699, 700–704, 714, 720
Launching 714, 715, 718, 719
Production 720–724
Recovery 714, 716, 721, 727, 729, 730, 768
Reentry 697, 704, 714, 727, 728, 730, 912, 913, 916
Components and subsystems 720
Control systems 714, 720
Escape system 697, 703, 704, 705, 710, 711, 714, 720, 724
Flight test program 704, 724, 727
Future operations schedule 745, 746
G-forces 724, 727, 731, 735
Heat shields 714, 720
Instrument panel 700, 701
Little Joe booster 704, 710, 712
Manned orbital flight 703
Parachute 697, 704, 710, 720, 745
Pilot's role 700, 701, 735
Prime contractor 720
Priority 745
Progress, summary 745
Research and development program 703–720
Airplane drop tests 704, 707–709, 745
Full-scale capsule models 704–709, 745
Wind tunnel testing 704
Redstone 704
Retrorockets 697–700, 720, 730
Scanners, horizon 697, 720
Separation rockets 697–699, 703
Subcontractors 720
Tests with animals 710, 713, 714, 724, 727
Tracking 730, 768
Trajectories 697, 700, 702, 703, 724, 727, 728

Page

Metals:
Liquid ... 816, 819, 848, 983, 986
Refractory ... 847, 849–852
Meteorites ... 613–615
Meteoroids ... 654, 819, 857, 863–865
Resistant materials ... 848, 853
Simulation in ground facilities ... 863–865
Meteorological satellites ... 643–668, 786
NASA program ... 646, 647
Stability ... 649, 656, 657
Meteorology (*see also* Atmospheres) ... 643–668
Meteors ... 586, 613–615, 863–865, 945
Methane ... 584, 905
Micrometeoroids. (*See* Meteoroids.)
Micrometeorites ... 613–615, 621
Midas I, II ... 1001, 1005
Minitrack ... 754, 757, 761, 762, 770
Minuteman (Air Force) ballistic missile ... 935, 951
Missile test ranges ... 754, 768
Missiles:
Air-to-air ... 935
Air-to-ground ... 935
Antimissile ... 965–970
Launching ... 967
Control ... 967
Flight path ... 967
Wind tunnel tests ... 967
Antisatellite ... 970
Ballistic (*see also* specific types, e.g., Atlas, etc.) ... 835, 841, 843–845, 909, 912, 932, 935
Base heating ... 938
Defense systems ... 965–970
Interceptors ... 965–970
Intercontinental (ICBM) ... 835–837, 841, 843, 943, 967, 968
Intermediate range (IRBM) ... 943
Launching ... 936, 938–940
Nose cones ... 941
Reentry ... 941, 943–945
Short range (control) ... 936
Stability, static ... 943, 945
Trajectories ... 941–943
Control ... 936
Design ... 932, 935–941
Ground-to-air ... 935
Ground-to-ground (winged) ... 935
Loads ... 961, 963
List of specific missiles studied by NASA ... 935
NASA, general research program ... 935
Programs, military ... 777
Moon ... 591, 610, 615–616, 617–618, 629, 632, 636–637
Atmosphere ... 575, 580, 582
Exploration ... 615–624, 786, 800–802, 865
Landings ... 786, 791
Television reconnaissance ... 618
Mossbauer effect ... 608
Mylar ... 656, 669, 861
Molybdenum ... 847, 850, 851, 905, 919
Molybdenum alloys ... 919

N

National Aeronautics and Space Administration (*see also* individual research center, e.g., Ames, etc.; and National Advisory Committee for Aeronautics):
Air Force cooperation in testing Nova engine ... 979–981
Bioscience Advisory Committee, list of members report ... 971

National Aeronautics and Space Administration—Continued Page
Cooperation with AEC on nuclear rocket 827, 830, 831
Cooperation with DOD and Weather Bureau 646
Cooperation with DOD in VTOL research 867–869
Cooperation with industries 647
Cooperation with universities 647
Ionosphere research program 588
Launch vehicle program 777–791
Lunar and planetary exploration programs 617–624
Meteorological satellite program 646–647
Office of Life Science Programs 971–975
Objectives 971–972, 975
Responsibility in life sciences 971
Ten-year plan 972
NACA. (*See* National Advisory Committee for Aeronautics.)
NADC. (*See* Naval Air Development Center.)
NASA. (*See* National Aeronautics and Space Administration.)
National Advisory Committee for Aeronautics agreement with Air Force on X–15 928
National Meteorological Center, U.S. Weather Bureau 646
Naval Air Material Center, Philadelphia. (*See* Air Crew Equipment Laboratory.)
Naval Photographic Interpretation Center 656
Navy, Department of 656, 664, 697, 700
Navaho (Air Force) ground-to-ground missile (winged) 935
Nebulae 610–611, 616
Bright 611
Solar 611
Nickel 853
Nickel alloys 849, 851, 929–930
Nike-Asp 639
Nike-Hercules (Army) 935
Nike-Zeus (Army) ground-to-air missile 935
Niobium (columbium) 847, 850–851, 919
Nitrides 850–851
Nitrogen 577, 580, 584
Nimbus, meteorological satellite 664–666
Noise (*see also* Sonic boom; Sound) 876, 887–890, 954, 956–957
Boundary layer 882–885
Engine 882, 878
Ground damage 885
Measurements 876–877
Radio 591
Reduction 878, 885–888
Rocket engine 888
Shock waves 882, 883, 885–887
Space vehicles 887–888
North American Aviation Corp 928
Northern lights. (*See* Aurora.)
Nose cones (*see also* Bodies, blunt bodies, conical) 941
Nozzles:
Exhaust 938
Rocket 938
Swiveled 941
Nova 791, 794, 977–979
Cost 981
1½-million-pound-thrust engine 977–982
Payload 977

O

Office of Life Science Programs. (*See* NASA.)
Office of Naval Research 638
Orbital flight, manned 967, 724, 727, 729, 730, 745
Orbiting astronomical laboratory 636

Page
Orbits ... 605, 617, 619, 689, 695, 754, 756, 757, 768, 773
Communication satellite ... 674
Equatorial ... 749, 750
High inclination ... 764
Mercury project ... 714, 727–730
Polar ... 749, 750, 764
Twenty-four hour ... 674, 821
Oxidation ... 919
Oxides ... 850, 851
Oxygen ... 577, 786, 981
Ozone ... 577

P

Pacific Missile Range ... 756, 757, 764
Paddlewheel. (*See* Explorer VI; Pioneer V.)
Particle accelerators ... 807, 808, 863, 865
Particles, energetic ... 586–588, 591, 594–599, 613–614, 632, 634, 635, 654, 798, 865
Particles in space ... 613–616
Patrick Air Force Base, Fla ... 965
Payloads:
Medium weight ... 786
Scientific ... 681
Lunar probes ... 617, 618, 619, 620, 621
Planetary probes ... 619, 620, 621
Pershing (Army) ballistic missile ... 935, 938
Perturbations ... 687, 689, 690, 691
Photography (*see also* Television; Cameras): Cloud cover ... 647–651, 654–663
Pinch effect ... 814
Pioneer III ... 634, 992
Pioneer IV ... 620, 634, 641, 994
Pioneer V ... 616, 619–621, 1002
Planetary orbiters ... 617, 619
Planets ... 632, 636
Atmospheric entry ... 835–846
Biology ... 637–638
Exploration ... 617–624
Television reconnaissance ... 620
Plasma (*see also* Rockets, plasma; Propulsion, plasma):
Definition ... 812
Sheath ... 967
Plasma accelerators ... 812–815
Plastics ... 669, 853, 859, 861, 916, 950
Point Arguello. (*See* Pacific Missile Range.)
Polaris (Navy) ballistic missile ... 935, 938, 948, 950
Potassium ... 848, 983
Pound, Robert V ... 608–610
Power sources:
Fission ... 824
Nuclear ... 819, 821, 822, 981–986
Solar ... 685, 816, 817, 848, 864
Power supplies ... 683, 685
Pressure suits ... 740–741
Project Mercury. (*See* Mercury project.)
Propellant tanks. (*See* Fuel tanks.)
Propellants. (*See* Fuels.)
Propulsion ... 777–834
Chemical ... 791, 797, 821, 824
Electric ... 791, 796, 797, 798
Ion ... 805–811
Nonchemical ... 797
Nuclear ... 981–986
Nuclear electric ... 798, 799, 847, 865
Plasma ... 798, 799
Space ... 791–804
Propulsion systems, weight problem ... 798, 800
Protective coatings ... 851, 905, 919
Pumps ... 831, 930, 981, 983

R

Page

Radar 649, 651, 654, 967, 968
Radiation 586, 613, 621, 651, 653, 824, 837, 857, 865
  Cosmic 596, 611
  Infrared 649, 651, 667
  Measurements 651, 653
  Solar 626, 651–654, 667
  Thermal 651, 653, 865, 914, 916, 918
  X-ray 654
Radiation belt 588, 599, 600, 632, 634, 638, 837
Radiation hazards 973, 975
  Resistant materials 848, 853, 854
Radiation shielding 824, 844, 845, 865, 951, 974, 983, 986
Radiators, space 853
Radioisotopes 819
Radio sounding 591–594, 643, 644
Radio transmission 671, 683
Radio waves 586, 591, 611, 613, 616, 669, 671
Rascal (Air Force) air-to-ground missile 935
Reactors, nuclear 819, 821, 824, 825, 831, 848, 983–986
Rebka, Glen A 608, 610
Recruit (Engine) 714
Redstone (Army) ballistic missile 935
Redstone ballistic flights 724, 726, 727
Redstone booster 704, 724, 745, 746
Reentry (*see also* Entry) 697, 703, 704, 727, 728, 730, 745, 837, 838, 839, 848, 910–914, 916, 922, 932, 941, 943, 944, 945, 964, 965, 967–969
Regulus II (Navy) ground-to-ground missile 935
Relativity, theory of 608, 632
Retrorockets 697–700, 720, 730
Rockets:
  Chemical 797, 798, 821, 824, 968, 970
    Liquid 977–981
    1½-million-pound-thrust booster 977–982
  Clustered 779, 791, 797
  Electric 797, 803, 805
  Ion 803, 805–811
  Multistage 827
  Nuclear 797, 798, 824, 826, 827–829, 831, 834, 847, 849, 851, 865
  Plasma 803, 812–814
Rocketdyne (North American) 977, 979
Rotors 872
Rubidium 848
Russia. (*See* Soviet Union.)
Ryan Aeronautical Co 869

S

SNAP–2 ..... 819, 820
SNAP–3 819
SNAP–8 831–824
STOL. (*See* Airplanes, STOL.)
San Diego, Calif 770
Santa Susan 979, 981
San Salvador 756
Satellites 575, 591, 593, 611, 634–636, 667–668, 835, 970
  Antisatellite missiles 965, 970
  Communications 669–677, 821
  Dark (*see also* Echo.)
  Erectable 857–859
  Geodetic 605, 685–696
  Inflatable 669
  Reconnaissance (defense) 970
  Scientific 640–641, 786
Saturn 583, 619, 621, 791–793, 831, 964, 977
Schina, Walter Marty, Jr., biography 743
Score, Project (Atlas) 993

Page

Scout 640–642, 779–781, 863, 964–965
Shepard, Alan Bartlett, Jr., biography 743–744
Shielding. (*See* Radiation shielding.)
Short takeoff and landing. (*See* Airplanes, STOL.)
Shot Put 861
Skids 929, 965
Slayton, Donald Kent, biography 744
Smithsonian Astrophysical Observatory 773
"Smokestack oscillation". (*See* Wind effect.)
Snark (Air Force) ground-to-ground missile (winged) 935
Sodium 639, 848, 983
Sidewinder (Navy) air-to-air missile 935
Solar energy. (*See* Power sources, solar.)
Solar system, age and origin (*see also* Sun) 610, 615, 633
Sonic boom 882, 885–887
Sounding rockets 575, 578, 579, 586, 639, 643, 647
South Africa 757, 764, 770
South America 770
Soviet Union satellite data 586–589
Space cabins. (*See* Capsules; Space stations, manned.)
Space communications 588, 591, 620, 677–685, 888
  Antennas 677, 683
  Ground receiving equipment 677
  Power requirements 677–681
Space environment 611, 613, 857, 859, 861, 863–865, 971–973, 975
Space exploration (*see also* Space probes) 611
Space flight. (*See* Interplanetary flight; Lunar flight; Spacecraft, manned.)
Space medicine education 975
Space medicine research 731, 971–975
  Behavioral sciences 972, 974–975
  In-flight:
    Ground-based 974–975
    Space biology 972, 975
Space probes 611, 616, 635, 641, 749, 754, 779, 797, 800, 801, 972–975
Space sciences:
  Discoveries 638
  NASA research objectives 632–633
  Vehicle summary 642
Space stations 618, 861, 862, 863
Space structures 855–866
Spacecraft 591, 865, 866
  Erectable 857–859
  Ferry 863, 867
  Ground handling 752, 888
  Inflated 859, 861
  Landing 855
  Materials 859
  Noise 887, 888
  Weight factors 855, 857
Spacecraft, manned (*see also* Mercury project) 619, 697–746, 791, 835–839, 841, 865, 971–975
Spacecraft configurations 745, 857, 861, 863, 865, 867
Sparrow (Navy) air-to-air missile 935
Spectrum 611–613
  Absorption 613
  Electromagnetic 611–612, 974, 975
  Infrared region 611–613, 616
  Ultraviolet region 611–613, 616
Sputnik I, II, III, IV 988, 990, 1005
Stability 943, 945–946
  Hypersonic gliders 909
  Missiles 941
  Supersonic airplanes 892, 984, 897, 900
Stars 615, 636, 691, 695
Stennis, Senator John, letter of submittal from Dr. Glennan to III
St. John's, Newfoundland 764

Page

Storms ... 643, 645, 647
Strong (Navy destroyer) ... 720
Structural loads. (*See* Loads.)
Structures ... 669, 816, 818, 848, 861, 878, 881–882, 884, 888, 916, 917, 919, 935, 957, 964
  Erectable ... 857, 859, 861
  Flexibility ... 957
Sulfur ... 611, 613
Sun ... 575, 577, 584, 588, 605, 610, 632–635, 651, 664, 797

T

Talos (Navy) ground-to-air missile ... 903, 935
Tantalum ... 847, 850, 851, 919
Telemetry ... 578, 594, 616, 681, 752, 754, 756–757, 929–930
Television ... 618–620, 651, 654, 656, 667, 668, 677, 681
Ten-year plan, NASA ... 972
Test facilities. (*See* Facilities, test.)
Texas, University of ... 713–714
Thor (Air Force) ballistic missile ... 642, 647, 779, 935, 948, 950, 977
Thor-Able ... 619, 620, 640, 656, 779, 787
Thor-Agena ... 641
Thor-Agena B ... 664, 667, 779, 786
Thor-Atlas ... 641
Thor-Delta (*see also* Delta) ... 619, 640
Tiros ... 668, 671
Tiros I ... 649, 654–657, 658–662, 664, 665, 1003
Titan (Air Force) ballistic missile ... 779, 935, 938
Titanium ... 847
Tracking ... 645, 656, 657, 677, 683, 685, 752, 754–775, 965
Tracking stations ... 654, 752, 754, 756, 757, 761, 764, 768, 770
  Baker-Nunn camera ... 757, 760
  Bell Telephone Laboratories, Holmdel, N.J ... 671
  Deep space ... 764, 767, 768
  Fort Monmouth, N.J ... 657
  Goldstone, Calif ... 671, 764, 766
  Johannesburg, South Africa ... 764
  Kaena Point, Hawaii ... 657
  Mercury ... 769
  Millstone ... 671
  Minitract ... 757, 761, 770
  Woomera, Australia ... 764
Trajectories (*see also* Orbits) ... 724, 727, 835, 837, 840
  Ballistic missile ... 941–943, 945
  Hypersonic vehicle ... 910–913
  Space ... 749–750, 754
Transit I–A, I–B, II–A ... 998, 1004, 1005
Transports. (*See* Airplanes, transport.)
Tungsten ... 807, 847, 850–852, 919

U

U.S.S.R. (*see also* Soviet Union) ... 586, 588
Universe:
  Age and origin ... 610, 633
  Description ... 635
  Expansion of ... 610
Uranium ... 824

V

V–2 rockets ... 578
VTOL. (*See* Airplanes, VTOL.)
Vanguard ... 605, 639, 640, 777, 779, 988–991, 995, 996
Vanguard I ... 689, 691, 695, 989
Vanguard II ... 640, 649, 650, 993
Vanguard III ... 640, 999
Vanguard launching vehicle ... 640
Vega ... 786

Page
Venus ..... 580, 581, 586, 605, 616–620, 624, 637, 638, 791, 797, 800, 801, 841, 842, 846.
Verne, Jules 835
Vertical takeoff and landing. (*See* Airplanes, VTOL.)
Vibration (*see also* Flutter) 878, 881, 882, 936, 939, 965
Viscount (Vickers) 903

W

W–2 molybdenum alloy 919
Wallops Island, Va 710, 756, 861, 936, 965
Warheads 968, 970
Waves, shock 882, 883, 885–887, 892, 938, 940, 947
Weather Bureau (U.S.) 646, 664
Weather satellites. (*See* Meteorological satellites.)
Weightlessness 724, 727, 739, 857, 924, 929, 930, 973
Wendover, Utah 930
Western Electric Co 768
Wind effect 578, 649, 936, 939, 951, 954, 956, 961, 965
Wind tunnel tests 936, 938, 957, 960, 967
Wings, variable geometry 897–901
Woomera, Australia 764
Wright Air Development Center 731

X

X–1 (Bell) 926, 928
X–2 (Bell) 910, 929
X–5 (Bell) 897
X–15 (North American) 910, 922, 924, 926, 927, 928–930, 934, 936, 964, 965
X–13 (Ryan) 872, 875
X–14 (Bell) 872, 875, 876
X–18 (Hiller) 869
XF–109 (Bell) 872, 875
XLR–99 (engine) 932
XV–1 (McDonnell) 872, 873
XV–3 (Bell) 872, 873, 876

Z

Zero-g. (*See* Weightlessness.)

○